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SYSTEMS ENGINEERING CAPSTONE PROJECT REPORT

TRANSPORTATION ANALYSIS EXPLORING ALTERNATIVE SHIPPING OF MARINE EXPEDITIONARY BRIGADE FORCES TO SEABASE IN CONTINGENCY RESPONSE SCENARIOS

by

Team MARFORPAC
Cohort SE311-142M

December 2015

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As the U.S. national security policy shifts focus toward the Pacific theater and limited availability of amphibious shipping, Marine Forces Pacific must consider the augmentation of alternative shipping to deploy forces to a seabase location to support military operations in the Pacific Command area of operations. Implementing a model-based systems engineering approach, this capstone project examines the effects of augmenting amphibious shipping with commercial, allied nation, and military sealift command ships to achieve force closure at a seabase and reduce fuel consumption. Multiple shipping alternatives supporting a Marine Expeditionary Brigade in anti-access/area denial (A2/AD) and humanitarian assistance/disaster relief (HA/DR) missions formed the basis for measuring the effects of augmenting amphibious shipping. A simulation was developed to model the operational scenarios, and statistical analysis was performed upon the results of each alternative to identify factors affecting force closure time and fuel consumption. Analysis indicated that the effects of augmenting amphibious shipping vary based upon the mission type. Significant statistical evidence suggests that augmentation of amphibious shipping reduces force closure time and fuel consumption for the A2/AD mission. Based on the research, further investigation into the effects of augmented shipping on the Assembly and Employ phases of seabasing operations is recommended.

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Cohort SE311-142M/Team MARFORPAC

Submitted in partial fulfillment of the
requirements for the degrees of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING

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As the U.S. national security policy shifts focus toward the Pacific theater and limited availability of amphibious shipping, Marine Forces Pacific must consider the augmentation of alternative shipping to deploy forces to a seabase location to support military operations in the Pacific Command area of operations. Implementing a model-based systems engineering approach, this capstone project examines the effects of augmenting amphibious shipping with commercial, allied nation, and military sealift command ships to achieve force closure at a seabase and reduce fuel consumption. Multiple shipping alternatives supporting a Marine Expeditionary Brigade in anti-access/area denial (A2/AD) and humanitarian assistance/disaster relief (HA/DR) missions formed the basis for measuring the effects of augmenting amphibious shipping. A simulation was developed to model the operational scenarios, and statistical analysis was performed upon the results of each alternative to identify factors affecting force closure time and fuel consumption. Analysis indicated that the effects of augmenting amphibious shipping vary based upon the mission type. Significant statistical evidence suggests that augmentation of amphibious shipping reduces force closure time and fuel consumption for the A2/AD mission. Based on the research, further investigation into the effects of augmented shipping on the *Assembly* and *Employ* phases of seabasing operations is recommended.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	anti access/area denial
AO	area of operation
AOR	area of responsibility
APEX	Adaptive Planning and Execution
APOD	aerial ports of debarkation
ARG	amphibious ready group
CMC	Commandant of the Marine Corps
CONPLAN	contingency plan
DOD	Department of Defense
E2O	Energy Efficiency Office
FDP&E	force deployment planning and execution
HA/DR	humanitarian aid/disaster relief
HQ	headquarters
IPR	in-progress review
JOPES	Joint Operation Planning and Execution System
JOPP	Joint Operation Planning Process
MAGTF	Marine Air Ground Task Force
MARFORPAC	Marine Forces Pacific
MBSE	model based systems engineering
MCO	Marine Corps Order
MCSC	Marine Corps Systems Command
MEB	Marine Expeditionary Brigade
MEU	Marine Expeditionary Unit
MPF	Maritime Preposition Force
MOE	measure of effectiveness
MPSRON	Maritime Prepositioning Squadron
MPSRON-3	Maritime Prepositioning Ships Squadron-3
MSC	Military Sealift Command
NCA	National Command Authority
POM	Program Objective Memorandum

SEA	systems engineering analysis
SPOE	sea port of embarkation
SPOD	sea port of debarkation
USMC	United States Marine Corps
USPACOM	United States Pacific Command
WARNORD	warning order

EXECUTIVE SUMMARY

This capstone report supports the needs of two United States Marine Corps Sponsors: Marine Forces Pacific (MARFORPAC) and the Marine Corps Expeditionary Energy Office (E2O). Marine Forces Pacific approached the Naval Postgraduate School (NPS) to provide a capability to model deployment scenarios and perform trade-off analysis between naval, maritime and commercial shipping based upon expediency of expeditionary forces arriving at a designated seabase. Expeditionary Energy Office approached NPS to provide a capability to predict energy consumption of the Marine Expeditionary Force in support of reducing dependency on fossil fuels in a deployed environment. The needs of these two independent sponsors were combined based on planning guidance from the 35th and 36th Commandants of the Marine Corps (CMC) emphasizing the need to reduce fuel consumption during Marine Air Ground Task Force (MAGTF) operations and identify alternative shipping to augment the Navy's 33 ship amphibious force (Amos 2010; Dunford 2015). Based on the CMC planning guidance and the sponsors capability needs specific research questions were established to frame the scope of research to the assessment and selection of fuel efficient alternative shipping sufficient to transport Marines and their equipment from home port to seabase during a range of military operations.

The Systems Engineering Cohort SE311-142M Team, composed of five Marine Corps civilian students, utilized a Model Based Systems Engineering (MBSE) methodology to investigate the problem space, identify requirements, develop alternative solutions, and compare these alternatives with respect to combinations of vessels and ship packages that provide both mission success and measureable energy efficiency. The MBSE methodology starts with a need for combat systems effectiveness as system characteristic inputs to a combination of measures that enable the tradeoff between energy efficiency and vessel selection and are measured in "force closure time" and "fuel consumed at force closure." This report integrates processes and tools such as systems architecting and development, simulation technologies, and advanced statistical analysis

to demonstrate ways to examine impacts of sea vessel tradeoffs, and include consideration of system effectiveness in multiple criteria trade space analysis.

Following the initial research, stakeholder analysis and functional analysis, the team scoped the research to humanitarian assistance/disaster relief (HA/DR) and anti-access/area denial (A2/AD) missions. Specific focus was on the Maritime Preposition Force (MPF) operations phases of *Planning*, *Marshaling and Movement*, and *Arrival* in order to accomplish the *Close* phase of seabasing operations (United States Marine Corps 2009). These combinations of ship packages, shown in Table 1, provided a sufficient set of shipping combinations from naval amphibious fleet, Maritime Sealift Command (MSC) maritime prepositioning ship squadron, commercial, and allied nation shipping to analyze force closure and fuel consumption from the seaport of embarkation (SPOE) to the seabase. Further detailed descriptions of these ships are included in Chapter IV.B of this report.

Table 1. Scenario Alternatives and Ship Compositions

Alternatives	Composition of Ships			
HA/DR #1	Amphibious • LHD x 2 • LSD x 2 • LPD x 1	MSC • T-AKE • LMSR • MLP		
HA/DR #2	Amphibious • LHD x 2 • LSD x 1 • LPD x 1	MSC • T-AKE • LMSR • MLP		Commercial • Maersk AFSB • HSV Swift
A2/AD #1	Amphibious • LHD x 4 • LSD x 3 • LPD x 3			
A2/AD #2	Amphibious • LHD x 2 • LSD x 2 • LPD x 2	MSC • T-AK x 3 • T-AKE • LMSR x 2 • MLP	Allied Nation • Canberra	Commercial • Cruise Liner
A2/AD #3	Amphibious • LHD x 1 • LSD x 1 • LPD x 1	MSC • T-AKE x 1 • LMSR x 1 • MLP x 1	Allied Nation • Canberra	Commercial • Cruise Liner • Maersk AFSB • MV Blue Marlin

The objective was to represent transportation alternatives in a simulation model to support systems engineering analysis; allow comparisons of various transportation approaches; and identify trade-space between transportation methods, time to close force at seabase, and fuel consumption. The capstone team performed a systems engineering analysis of the application of amphibious, military sealift command, allied nation, and commercial shipping, as a means to move personnel and equipment from the unit's garrison location or forward deployed location to a designated seabase location in support of military operations. Two measure of effectiveness (MOE) supported further systems engineering analysis. The first measure – MOE1 – focused on Total Fuel Consumption measured in gallons. The second measure – MOE2 – Total Time to Close Force at Seabase measured in hours . These MOEs were applied to both HA/DR and A2/AD to identify the impacts, measured as fuel consumption at force closure and time to force closure, when selecting alternatives to traditional/doctrinal methods of transporting personnel and equipment to a seabase.

Each scenario has a separate definition of force closure. For HA/DR, it represents delivery of a specific amount of supplies based upon number of refugees. For A2/AD, force closure is the delivery of 80% of material from the MEF equipment density list to the seabase (Operational Analysis Division, Headquarters Marine Corps Combat Development and Integration 2013). ExtendSim, a discrete event simulation software, was used to model vessel transit from SPOE to seabase for the selected missions and ship packages. The effects of environmental factors such as "sea state" on "speed" were included in the model to introduced random variability and take into account factors that can affect the speed of vessels in transit. Analysis revealed little statistical difference between the two HA/DR alternatives. Specifically, the analysis confirmed that there is a statistically significant positive correlation between the number of ships at force closure and the total fuel consumed at force closure. In addition, there was a statistically significant positive correlation between average horsepower and total fuel consumed at force closure. Force closure time had a strong negative correlation between average speeds to force closure versus time to force closure, leading the team to conclude that for the HA/DR scenario and ship package combinations there were no benefits observed in

terms of time to force closure or fuel consumed when augmenting the force with commercial shipping. Analysis of the three A2/AD alternatives showed similar statistics for number of ships at force closure and total fuel consumed and average horsepower to total fuel consumed. There was significant statistical evidence to support the hypothesis that the ship packaging in the A2/AD alternatives had different means. Furthermore, the Marine Expeditionary Brigade (MEB) Amphibious Ready Group (ARG) augmented by commercial shipping results in the mean time for force closure reduced by 70%. Similarly, fuel consumption is reduced by 80% when the MEB ARG is augmented with commercial shipping. For the A2/AD mission and force closure definition, the advantages of augmenting with commercial shipping are beneficial to reducing force closure time and conserving fuel.

The analysis performed allowed the capstone team to answer the research questions posed at the beginning of the project. The capstone team determined that (1) the augmentation of alternative shipping platforms mission demonstrated faster force closure times and reduced fuel consumption for the A2/AD mission; (2) there is a measurable trade space between force closure and fuel consumption; and (3) sea state and the number of ships influenced fuel consumption while speed and distance influenced force closure time. Recommended follow-on research into the time to complete the *Assembly* and *Employ* phases of the seabasing operations will provide further insight into the effectiveness of augmenting Naval amphibious ships with alternative shipping platforms and its impact upon ship-to-shore movement.

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I. INTRODUCTION

A. OVERVIEW

The Marine Forces Pacific (MARFORPAC) Science Advisor contacted Naval Postgraduate School (NPS) to research ideas leading to the selection of alternative sea going vessels. The alternatives selected had to be sufficient to transport Marines and their material from homeport to a seabase in support of a range of military operations, specifically A2/AD and HA/DR missions. In addition, the United States Marine Corps Expeditionary Energy Office (E2O) contacted NPS to research ideas for improving energy efficiency while conducting the missions of a Marine Air Ground Task Force (MAGTF). These complimentary research areas were combined into this capstone project resulting in research supporting the assessment and selection of fuel-efficient alternative shipping that is sufficient to transport Marines and their equipment from homeport to seabase. This document presents the results obtained by the capstone team through the application of a Model Based Systems Engineering (MBSE) approach.

B. BACKGROUND

This project utilized a multi-disciplinary MBSE approach to develop a methodology that started with the need for combat systems effectiveness as system characteristic inputs to a combination of measures that enable the tradeoff between energy efficiency and vessel selection. We integrated processes and tools such as systems architecture and development, various simulation technologies, and advanced statistical design of experiments to demonstrate ways to select combinations of vessels and ship packages that provide both mission success and measureable energy efficiency. We examined impacts of sea vessel tradeoffs, and included consideration of system effectiveness using multiple criteria and trade space analysis.

The focus of this project was to examine MARFORPAC's expeditionary reach challenges as they relate to the movement of forces and equipment from various locations to a designated seabase in the MARFORPAC area of operation (AO). In support of "Marine Corps Force Deployment Planning and Execution Manual," our team of

engineers from Marine Corps Systems Command (MCSC) utilized a multi-disciplinary MBSE approach to model the use of traditional (e.g., naval) and alternative (e.g., commercial) methods to transport forces and equipment to a seabase within the MARFORPAC AO. This model enabled trade-offs between the time it takes forces to arrive on station (i.e., force closure time) and total energy consumption based upon the transportation modes selected.

This project builds upon previous capstone projects and expeditionary warrior (EW) wargames. Primary sources included:

- "Exploring the Reduction of Fuel Consumption for Ship-to-Shore Connectors of the Marine Expeditionary Brigade" (Super Group Cohort 311-122O 2013)
- "A Simulation Based Analysis of U.S. Army Watercraft Capabilities in a 2022 Foreign Humanitarian Assistance/Disaster Relief Operation" (Beery 2011)
- "Influence of Foreign Humanitarian Assistance/Disaster Relief in a Coastal Nation" (SEA Cohort 17A 2011)

Reports generated by the Wargaming Division, Marine Corps Warfighting Laboratory, specifically Expeditionary Warrior 2010, Expeditionary Warrior 2010, provided an operational context for this team to develop functional and physical architectures for A2/AD and HA/DR missions. These architectures enabled development and analysis of a discrete event simulation. The simulation examines the scope of ship transport possibilities and supports the definition of possible ship packages.

The team integrated systems engineering processes and tools, various modeling and simulation technologies, and advanced statistical design of experiments to demonstrate ways to provide an operational system design of naval platforms (military, commercial, and a combination of both) that allows for a responsive deployment of forces to the seabase (measured in time), as well as improvement in energy efficiency. The intent was to provide operational commanders and staff planners a way to evaluate the trade space between mission effectiveness (measured in the time to deploy capability) and energy efficiency (measured in fuel requirements) by modeling traditional and non-traditional transportation means.

C. PROBLEM STATEMENT

The Marine Corps recognizes that "amphibious ships provide the most capable and flexible means of deploying and employing Marines across the range of military operations" and that shore basing "does not substitute for Marine Air Ground Task Forces (MAGTFs) coming from the sea" (Dunford 2015, 12). However, the 36th Commandant of the Marine Corps' (CMC's) Planning Guidance has noted that there are "insufficient amphibious ships to meet the current combatant commander requirements across the range of military operations" (2015, 12). Per the CMC direction, "we need to modify traditional employment methods and augment amphibious warships by adapting other vessels for sea-based littoral operations" (2015, 12). Likewise, the United States Marine Corps Expeditionary Energy Strategy and Implementation Plan (Marine Corps Expeditionary Energy Office 2011) clearly identifies the CMC's commitment to meeting the Department of Defense (DOD) mandate to reduce its dependence upon fossil fuels in the planning and execution of Marine Corps missions.

MARFORPAC has no model to perform trade-off analysis based upon expediency of expeditionary forces/equipment to *Close* at a designated seabase location and calculate energy efficiency (i.e., measured in fuel consumption). Using the organizational construct of a MEB performing within the range of military operations (ROMO), MARFORPAC requires a modeling capability that allows adjustment of variables and parameters in order to determine the trade space for closure of forces at the seabase while considering the effect upon fuel consumption. A primary consideration for expeditionary deployments for MARFORPAC is the potential for an extremely large Area of Operations, resulting in very long distances required to deploy necessary forces to support the ROMO.

D. SCOPE

A systems engineering analysis was performed in order to solve the problem, looking at the use of amphibious, military sealift command, allied nation, and commercial shipping, as a means to move personnel and equipment from the unit's garrison location or forward deployed location to a designated seabase location in support

of military operations. The focus of the systems engineering analysis examined trade-offs between the transportation means, time of arrival at seabase location, and fuel consumption.

Using a tailored systems engineering process to support our analysis, the following tasks were completed:

- analyze Stakeholder needs and collect data.
- identify model assumptions and constraints.
- define the system boundary and construct a system context diagram.
- perform operational analysis and develop operational scenarios.
- perform functional analysis and construct a functional architecture.
- translate the functional architecture into a physical architecture.
- develop Measures of Effectiveness (MOE).
- develop a simulation model that allows a trade-off analysis between key attributes identified by MARFORPAC.

The project objectives included:

- identify alternatives to traditional/doctrinal methods of transporting personnel and equipment to a seabase
- represent transportation alternatives in a simulation model to support systems engineering analysis and allow comparisons of various transportation approaches
- identify trade-space between transportation methods, time to close force at seabase, and fuel consumption

E. STAKEHOLDERS

A *Guide to the Project Management Book of Knowledge* (PMBOK) defines a stakeholder as “an individual, group or organization who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project” (Project Management Institute 2013, 450). This capstone project has two key stakeholders as shown in Table 1, with their respective basic want or need concerning the success of the

project and any risks or concerns with the program in the event it does not succeed or meet the mission requirement.

Table 1. Stakeholders

Stakeholder	Type	Want/Need	Concerns
Marine Forces Pacific (MARFORPAC)	Sponsor	Provide capability to model deployment scenarios and perform trade-off analysis based upon expediency of expeditionary forces arriving at a designated seabase and/or land location (i.e., travel time from home station to designated seabase and/or land location) and energy efficiency (i.e., measured in fuel consumption planning)	- Use of alternatives to amphibious shipping to deploy to seabase - Unable to expeditiously deploy personnel and equipment to seabase location using traditional transportation means - Time of arrival at seabase (equipment and forces) based upon transportation options available
Marine Corps Expeditionary Energy Office (E2O)	Capabilities advocate	Reduced energy consumption of the Marine Expeditionary Force and reduced dependency on fossil fuels in a deployed environment.	- Fuel efficiency not considered in operational planning resulting in higher deployment/movement costs - Unable to support Marine Corps energy efficiency initiatives

F. RESEARCH QUESTIONS

The following research questions guided the study:

1. What transportation alternatives allow the fastest time to close at seabase?
2. What is the trade space between time to close, fuel consumption, and available connector platforms?
3. What are the critical parameters influencing the selection of sealift to transport a MEB to a seabase?

Questions 1 and 2 are specific questions asked by our MARFORPAC and E2O sponsors obtained during our initial stakeholder meetings. The MARFORPAC expressed a need to be able to assess multiple combinations of shipping alternatives to transport

Marines, equipment, and supplies to a seabase and meet force closure for a range of military operations. The MARFORPAC sponsor requested that the selection of shipping combinations not be limited to naval vessels but be able to expand to commercial alternatives. Assessment of commercial shipping provides MARFORPAC with additional alternatives should quantities of supplies, equipment, or personnel exceed the organic transport capabilities of naval amphibious and maritime prepositioning force (MPF). The E2O sponsor emphasis is fuel consumption and energy efficiency. Question 3 focuses on examining the parameters that drive the selection of shipping alternatives and fuel consumptions. An understanding of the dominant parameters and correlation across parameters provides the MARFORPAC and E2O areas for future analysis.

II. SYSTEMS ENGINEERING PROCESS

A. TAILORED SYSTEMS ENGINEERING PROCESS

The capstone team used a tailored systems engineering process to examine the problem, model the system, and analyze the trade space. This chapter describes that process in detail, the research questions, the literature review results and concept of operations supporting the systems engineering effort.

Based on a model by Blanchard and Fabrycky (2011), the team developed a tailored systems engineering process model. In the first step, Initial Research, the team conducted research including mission analysis and a stakeholder analysis in order to define the parameters of the alternative solutions and the customer needs for the system. The team conducted literature research in conjunction with stakeholder analysis to support scoping the problem space through identification of alternative shipping and providing an understanding of the Joint Operation Planning Process (JOPP). The team defined the problem statements and the scope of the project. Upon completion of stakeholder analysis and problem definition, the team focused on developing a concept of operations and scenarios/vignettes with input from stakeholders received in meetings with MARFORPAC sponsors and during the first In-progress Review (IPR). Functional analysis identified key functional requirements the system must address in order to support seabasing.

The next step, Problem Formulation, was to assess the capability and success of the system, so the team worked with stakeholders and capability advocates to develop MOEs. The team utilized initial research products to identify and assess model parameters in order to determine the priority of importance to the stakeholders. Upon selection of key modeling parameters, the team designed the formal model using ExtendSim software.

During Analysis of Alternatives, the team developed the model based on the design from the previous phase. The team then executed the model over a range of

scenarios and parameter settings. The team then analyzed the compilation of data, in the form of runs, from the previous phase.

The final phase was Implementation. This phase focused upon the analysis of modeling data where results were identified and supported through statistical analysis. Conclusions were drawn, recommendations were made, the model was documented, and the final report was submitted. Figure 1 is adapted from Blanchard and Fabrycky (2011) and outlines the sequence of the systems engineering tasks completed in this project.

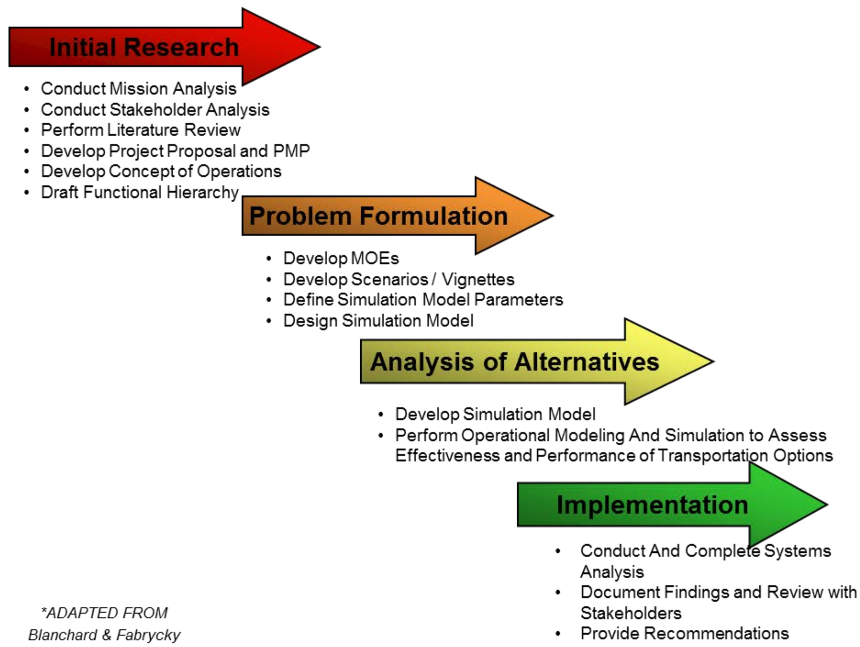


Figure 1. Systems Engineering Tasks. Adapted from Blanchard and Fabrycky (2011).

B. INITIAL RESEARCH

The literature research was conducted to scope the problem space through the identification of shipping alternatives. The research provided a description of vessel types and identification of key parameters related to shipping. The research also provided a deeper understanding of the JOPP and tools used by MAGTF planners. Lastly, the research provided tables and formulas needed to enable modeling of shipping kinematics and fuel efficiency computations.

The team initiated a literature search by reviewing the NPS studies and research proposal, “Applying a Model-Based Systems Engineering Methodology to Improve Expeditionary and Operational Reach for Marine Corps Forces,” to understand the background of the project. After initial research, the team conducted stakeholder research through an interview with the MARFORPAC Science Advisor and his team. The interview resulted in a rough problem definition and a briefing provided by the Science Advisor describing alternative shipping methods to consider. The capstone team began a literature search to refine our understanding of the problem through the exploration of the processes and role of a MAGTF planner, identifying the context of the problem, shipping alternatives and identifying modeling equations. *Joint Publication 3-35* provided details regarding the role and processes of MAGTF Planning (Joint Chiefs of Staff 2013). Review of the annual report for the “Program Objective Memorandum (POM) 2017 for Seabasing” and after-action reports from exercise Expeditionary Warrior for 2012 – 2014 provide the problem context. These source documents enabled the team to scope the context of the problem to both an A2/AD and HA/DR missions. The team explored the problem space for shipping alternatives that resulted in the identification of an on-line database of commercial shipping maintained by “Jane’s Merchant Ships.” This database provides a catalog of commercial shipping alternatives available to a MAGTF planner and characteristics of the vessels to support our design of experiment analysis.

Research was performed through a literature search on seabasing and amphibious vessels at the Gray Research Center, Marine Corps University Library. This identified a set of reports developed by the School of Advanced Warfighting School at Quantico, VA, analyzing amphibious transport and near term transport options. These reports provided insight into the operations issues surrounding sealift and the transport of material and Marines though Naval and commercial shipping. HA/DR scenario development was supported with data from the “Field Operations Guide for Disaster Assessment and Response” to determine quantities and types of humanitarian relief required for a given number of refugees (U.S. Agency for International Development 2005).

Model development was supported through additional research to determine the effects of sea state on vessel speed and calculate vessel fuel consumption. Sea state

versus speed calculations were developed based on the works of the second International Symposium of Marine Propulsions "Prediction of Speed Loss of a Ship in Waves" (Chaung and Steen 2011). Fuel consumption equations were developed based on the reports "Calculating Fuel Consumption" (Becker 2000) and "Reed's Naval Architecture for Marine Engineers" (Stokoe 2003).

C. ANALYSIS OF ALTERNATIVES

As part of the 36th CMC's Planning Guidance and direction, alternative shipping methods must be evaluated to try to augment current amphibious shipping capabilities (Dunford 2015). In order to understand the system boundaries of this project and to assist in analyzing the trade space, a series of alternative shipping methods were selected as the foundation in which all modeling and simulations were developed. The alternatives selected provide a sealift capability set that can support the lift requirements necessary for a medium-size MEB construct.

To establish a baseline for the trade space analysis, a combination of strictly amphibious warfare ships were chosen to support a seabase for a MEB sized element during an HA/DR or A2/AD missions. This would account for the transportation of all troops and supplies using strictly naval vessels from the shore to a seabase location and the institution of force closure. By establishing this baseline, subsequent comparisons could be made with other alternatives comparing force closure and fuel efficiency. The remaining alternatives looked at augmenting the amphibious baseline with different combinations of maritime preposition force ships, specifically Maritime Prepositioning Ships Squadron-3 (MPSRON-3), commercial and allied nation vessels. These alternatives provided another means of transporting troops, supplies, and equipment over traditional amphibious warfare ships to the seabase.

These alternatives were evaluated and served as the basis for scenario development, detailed in Chapter III, and serve as the foundation from which models were developed using ExtendSIM. In essence, the alternatives modeled supplement current seabase operations in the event current vessel availability is limited with a reduced amphibious warfare ship capability of 33 vessels and the possibility of multiple

contingency operations. According to General Dunford, “The 33 ship force accepts risk in the arrival of combat support and combat service support elements of the MEB, but has been adjudged to be adequate in meeting the needs of the naval force within today’s fiscal limitations” (United States Marine Corps 2015, 2). However, the alternatives provided represent several alternatives to fill the capability gaps associated with reduced amphibious warfare ships, as well as account for the possibility of a reduced MPF capability.

D. CONCEPT OF OPERATIONS

The concept of operations for the expeditionary transportation system begins with the occurrence of a crisis in the United States Pacific Command (USPACOM) area of responsibility (AOR). The National Command Authority (NCA) determines the appropriate military response and the Chairman, Joint Chiefs of Staff (CJCS) issues of warning order (WARNORD) to USPACOM with mission objectives and tentative C-Day and L-Hour. As part of Phase III crisis action planning, USPACOM develops a course of action (COA) in Joint Operation Planning and Execution System (JOPES) that includes Marine Forces Pacific (MARFORPAC) establishing a seabase location to deploy a MEB-sized Marine Air-Ground Task Force (MAGTF) (Joint Staff College 2000). The MARFORPAC planners determine the composition of the MEB-sized MAGTF through Adaptive Planning and Execution (APEX) and the Global Command and Control System (GCCS) appropriate for the assigned mission (Joint Chiefs of Staff 2013). MARFORPAC planners, with assistance from USPACOM and United States Transportation Command (USTRANSCOM) determine:

- seabase location
- available U.S. Navy amphibious shipping
- available Military Sealift Command shipping
- available alternative commercial shipping to transport personnel, equipment, and connectors

MARFORPAC planners modify existing operational plans (OPLANS) or contingency plans (CONPLACS) based upon:

- availability and capability of shipping
- time to close at seabase location
- fuel consumption
- connectors provided

Upon completion of planning, a deployment order is published and the commencement of seabasing operations begins (Headquarters, United States Marine Corps 2010). Figure 2 graphically depicts the high-level operational concept of crisis response, determining shipping alternatives to augment existing amphibious shipping capabilities, and deploying forces to a seabase location. The yellow arrows represent communication between system performers, the red arrows represent sealift options, and the gray arrows represent ship movement to the seabase location.

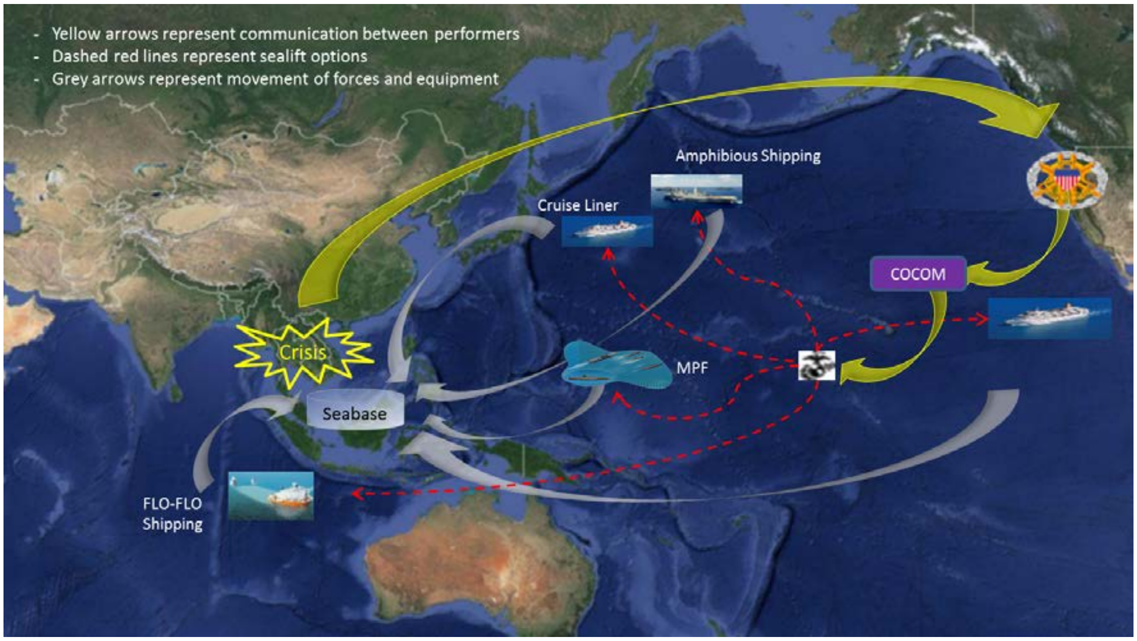


Figure 2. Alternatives to Amphibious Shipping High-Level Operational Concept Graphic—Operational View 1 (OV-1)

III. SCENARIO DEVELOPMENT

A. INTRODUCTION

In order to examine the effects of using alternative shipping on force closure time and fuel consumption, the analysis must recognize the impact of the mission type performed. From the "Seabasing Annual Report for Program Objective Memorandum 2017," a "seabase supports five (5) overlapping line of operations: Force Closure, Arrival and Assembly, Employment, Sustainment, and Reconstitution" (United States Marine Corps 2015, 4). *Joint Publication 3-35* states that "force closure occurs when the supported commander determines that the deploying force has completed the movement to the specified OA/destination with sufficient resources and is ready to conduct its assigned mission" (Joint Chiefs of Staff 2013, xx). Therefore, the mission assigned to the unit, and the unit's readiness to perform the mission greatly affect the force closure time. To consider various missions performed by the MEB, the capstone team selected a HA/DR and an A2/AD mission. Since the capstone team is not composed of military planners, the team based its scenarios using the reports Expeditionary Warrior 2012 and Expeditionary Warrior 2013, which both contained A2/AD scenarios to support a Marine Corps Title 10 exercise. Additionally, the team utilized the conclusion from Expeditionary Warrior 2012 to identify capability gaps in regards naval sealift capacity.

Expeditionary Warrior 2012 noted the "naval force's lack of capacity – mostly as a product of lift limitations" and that "this lack of capacity manifests itself in the finite shipboard space to embark troops and equipment, as well as the limited number of amphibious ships to execute operations" (Wargaming Division, Marine Corps Warfighting Laboratory 2012, 19). This exercise specifically focused on the use of alternatives due to a lack of amphibious ships. Expeditionary Warrior 2012 findings in conjunction with Expeditionary Warrior 2013 context provided realistic scenarios to examine the implementation of alternative shipping to meet force closure time and reduce fuel consumption as the MEB completed the first phase of seabasing: *Close* (United States Marine Corps 2015).

Expeditionary Warrior 2012 was divided into three distinct phases: Phase 1 – Achieve Access/Setting Conditions; Phase 2 – Gain Entry; and Phase 3 – Follow-on Operations (Wargaming Division, Marine Corps Warfighting Laboratory 2012). Since the scope of our capstone focused on establishing a seabase and meeting the criteria to achieve force closure, Phase 1 of Expeditionary Warrior 2012 and Expeditionary Warrior 2013 were used to develop the A2/AD and HA/DR scenarios. Force closure time would be determined when the MEB completed the *Close* phase of the seabasing operation.

As noted in the Expeditionary Warrior 2012 Final Report, the use of a seabase removes the "Iron Mountain" of sustainment, which must be transported and managed ashore (2012, 21). During Expeditionary Warrior 2012, the concern was that the use of a seabase "shifts the operational burden afloat and increases the force's overall fuel consumption" (2012). Comparison of APOD/SPOD vs. Seabasing fuel consumption was considered outside the scope of this capstone but could be a potential follow-on study.

B. A2/AD SCENARIO

Expeditionary Warrior 2012 provided an A2/AD scenario applicable to other littoral regions in the world. The capstone team modified the Expeditionary Warrior 2012 scenario by changing the geographic area of the mission (West Africa) to a location within the USPACOM AOR and created new fictitious names for the participating nations. This modification allowed the capstone team to focus on the challenges presented by the geographic expanse of the USPACOM AOR that the stakeholder, MARFORPAC, must consider. In the USPACOM scenario, the nation of Orange is a fictitious, politically unstable, allied nation in Southeast Asia threatened internally by an irregular enemy known as the Free Orange Movement (FOM). The South East Federation (SEF) is a neighboring nation that possesses a conventional, multi-corps ground force and is an enemy of Orange, while the nation of Volta is a regional power that supports adversaries to U.S. intervention. The FOM (with assistance from SEF) initiates attacks to overthrow the Orange government; simultaneously, SEF initiates a ground invasion of Orange (Wargaming Division, Marine Corps Warfighting Laboratory 2012). Figure 3

depicts the A2/AD opposing force laydown with respect to the seabase location for the scenario.

Figure 3. A2/AD Opposing Force Laydown with Seabase Location Identified

In Expeditionary Warrior 2012, Sea Ports of Debarkation (SPODs) and Aerial Ports of Debarkation (APODs) were established on an island chain 600 kilometers from the crisis area. However, for examining the concept of seabasing using traditional amphibious and non-traditional (e.g., commercial) shipping, removal of the SPODs and APODs is necessary to allow establishment of a seabase off the coast of Orange. Composition of the MEB will come from forces assigned by MARFORPAC and transport provided by available amphibious, military sealift command, and augmented commercial shipping. Completion of the *Close* phase of the seabasing operation for the A2/AD mission occurs when 80% of the MEB Equipment Density List (EDL) has arrived at the seabase location (Operational Analysis Division, Headquarters Marine Corps Combat Development and Integration 2013). Task organization establishes the composition of the Marine Expeditionary Brigade and their associated EDL. With no fixed MEB EDL, the capstone team derived a MEB EDL based upon the EDL of the 15th Marine Expeditionary Unit (MEU) onboard the Boxer ARG (I MEF 2015). Basing the composition of the MEB on the aggregation of the 15th MEU, 31st MEU, and 13th MEU (Rein), the capstone team extrapolated a MEB EDL as depicted in Table 2.

Table 2. Derived MEB Equipment Density List for A2/AD Mission

MEB EDL	
Vehicle	134,114 Square Feet
Cargo	363,862 Cubic Feet
Transport Aircraft	69
AAV	42
Marines	7,921

C. HA/DR SCENARIO

Expeditionary Warrior 2013 provided an A2/AD scenario that could be easily modified into a HA/DR mission. The capstone team modified the Expeditionary Warrior 2013 scenario by introducing a natural disaster (earthquake with tsunami) during D-4 affecting the western coast of Karta, within the USPACOM AOR. This modification allowed the capstone team to focus on the challenges presented by a HA/DR mission and the geographic expanse of the USPACOM AOR that our stakeholder, MARFORPAC, must consider.

Figure 4. Karta Nation

The modified scenario is based upon the nation of Karta, shown in Figure 4, a fictitious nation and a longtime political ally of the U.S., located in Southeast Asia. Karta has a population of approximately 294,000,000. The capitol is Jakarta and the nation has a robust infrastructure. On December 26, 2025, a magnitude 9 earthquake occurs in the Java Sea. The earthquake generates a Tsunami that hits the Karta coasts. Figure 4 shows the earthquake center and coast line impacted by the tsunami as well as refugee locations. The result is massive deviation and collapse of the nation's infrastructure. Initial assessment put the casualties at 130,000 deceased and 500,000 displaced. The King of Karta requests aid from the United States and the President orders USPACOM to initiate immediate humanitarian relief. United States Pacific Command establishes a joint task force, JTF-536 Headquarters (HQ) at Jakarta. The JTF-536 HQ confirms the causalities and reports that internal tensions between the Karta King and his brother are further destabilizing the region, making establishment of distribution points within the country risky. The possibility of a coup establishing the King's brother, who is anti-U.S., is likely. Given the loss of infrastructure and regional instability, C7F orders the establishment of a seabase to support the HA/DR mission. HA/DR equates to immediate and substantial aid to support the local population.

Two response scenarios were developed to support analysis of the HA/DR mission. The first employs a traditional set of military equipment comprised of amphibious and MPSRON assets. The second scenario employs commercial vessels to augment the response force. These two scenarios provide a force composition sufficient to analyze the effectiveness of augmenting the traditional amphibious force with commercial shipping. The HA/DR force composition is listed in Table 3.

Table 3. HA/DR Scenario Force Composition

Scenario	Unit Type	Unit Name	SPOE
1	LHD-6	Bonhomme Richard	Sasebo, JA
	MEU	15th	Afloat in Pacific
	MPF(SE)	MPSRON	Guam
2	AFSB	Maersk AFSB	Brisbane, Au
	HSV	Swift	Darwin, Au
	LHD-6	Bonhomme Richard	Sasebo, JA
	MEU	15th	Afloat in Pacific
	MPF(SE)	MPSRON	Guam

Force closure is calculated based on the number of affected refugees and the application of minimum substance rations derived from the "USAID Operations Guide" (U.S. Agency for International Development 2005), Systems Engineering Analysis (SEA) Cohort 17A (SEA Cohort 17A 2011) and Paul Beery thesis (Beery 2011). These documents defined the humanitarian aid as an initial supply plus a daily supply requirement. Therefore, Force closure is defined as the time required to provide tons of HA/DR supplies and water to the seabase. This is based on the work of SEA Cohort 17A, which concluded that, for a similar scenario, a total of 3.1 pounds of aid, per person, per day is required, along with a one-time need of 39.0 pounds per person (SEA Cohort 17A 2011). The USAID guide indicates that 15 liters of water is required per day, per refugee, to meet minimum survival standards. Given that 500,000 people are affected in the region of interest, a total of approximately 11,000 tons of aid and 8,000 tons of water are required. Time to Provide Aid is defined as the time for the HA/DR response force to transport 19,000 tons of aid to the seabase.

IV. SYSTEM ARCHITECTURE

A. SYSTEM FUNCTIONAL ARCHITECTURE

Based upon the problem statement, mission analysis, and concept of operations, the team developed a functional architecture to capture the functions, sub-functions, functional relationships, inputs, outputs, and functional flows of the system. The four phases of Maritime Prepositioning Force operations: “*Planning*, *Marshalling*, *Movement*, and *Arrival* and *Assembly*,” preclude MAGTF operations (United States Marine Corps 2009, 7). This provides the framework for the functions required to support expeditionary transportation using traditional (e.g., amphibious and MPF shipping) and alternative shipping methods as depicted in Figure 5. The capstone team focused on the first three high-level functions of the expeditionary transportation system: *Planning*, *Marshalling* and *Movement*, and *Arrival* as these are the functions performed in order to complete the *Close* phase of seabasing operations.

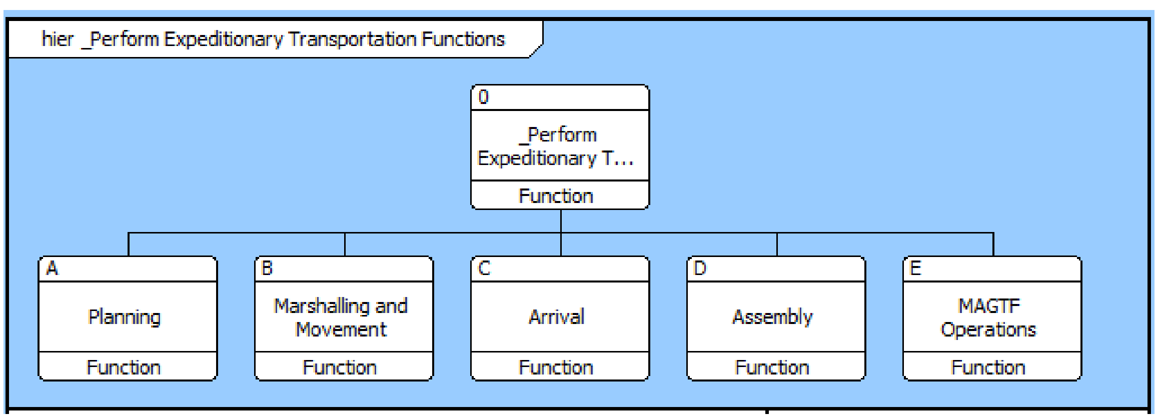


Figure 5. High-Level Functional Architecture

The decomposition of each high level function resulted in the identification of sub-functions that provided detail of the lower level functions performed within the expeditionary transportation system. The *Planning* function decomposed into three sub-functions:

- A.1 – Receive Warning Order
- A.2 – Determine Available Transportation
- A.3 – Allocate Equipment and Personnel

Functions A.1–A.3 represent the functions performed by the MAGTF planner, the MEB staff, and USTRANSCOM necessary to determine available transportation based upon the Warning Order and allocate personnel and equipment to those transportation assets. Figure 6 depicts functional hierarchy of the *Planning* function.

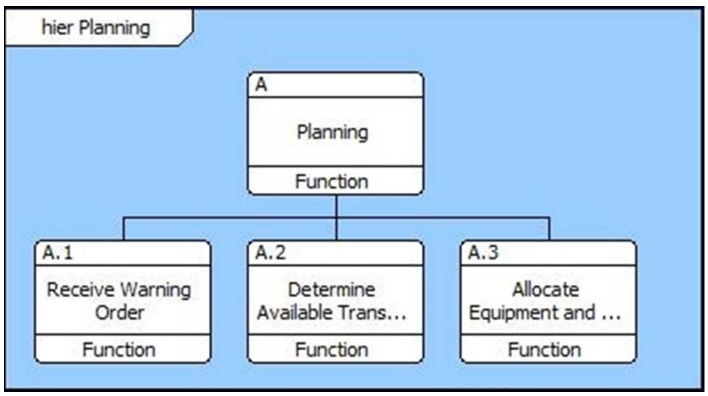


Figure 6. *Planning* Functional Hierarchy

The *Marshalling and Movement* function decomposed into five sub-functions:

- B.0 – Execute Deployment Order
- B.1 – Move to SPOE
- B.2 – Transit to SPOE
- B.3 – Embark MAGTF Assets
- B.4 – Transit to Seabase

Functions B.0–B.4 represents the functions performed to ensure the coordinated movement of shipping and MEB personnel/equipment to the SPOE for embarkation and subsequent transit to the seabase location. These functions account for the fuel required to transit to the SPOE and the time to embark the MEB onto the ships. Figure 7 depicts functional hierarchy of the *Marshalling and Movement* function.

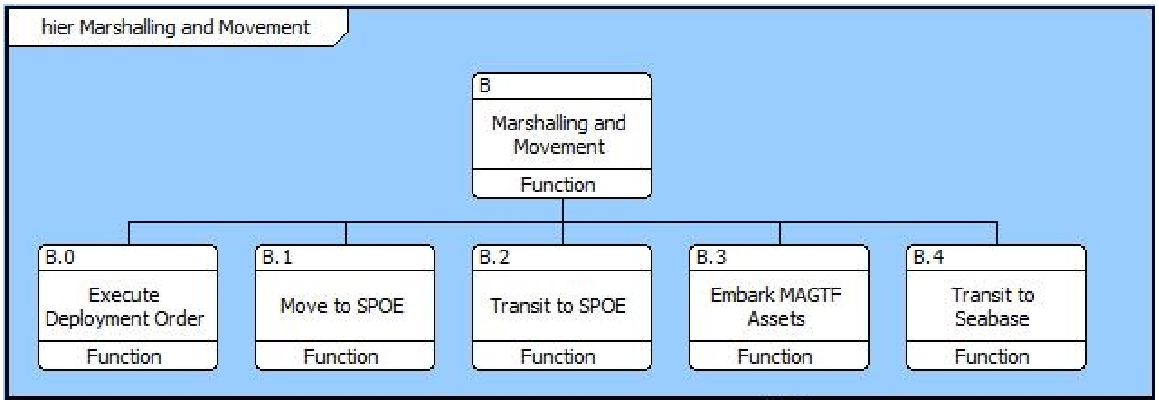


Figure 7. *Marshalling and Movement* Functional Hierarchy

The *Arrival* function decomposed into five sub-functions:

- C.1 – Arrival at Seabase
- C.2 – Determine Completion of Close Phase
- C.3 – Compute Fuel Consumption
- C.4 – Compute Force Closure Time
- C.5 – Provide Connectors

Functions C.1–C.5 represent the functions executed upon arrival to the seabase in order to determine the completion of the closing phase of the seabasing operation. The mission type determines the criteria for completing the *Close* phase of the seabasing operation and once achieved triggers the calculation of total fuel consumption and force closure time. *Arrival* at the seabase also marks the introduction of connector platforms into the seabase location. The provision of connector platforms with the completion of the *Close* phase marks the transition to the *Assembly* phase of the seabase operation. Figure 8 depicts the functional hierarchy of the *Arrival* function.

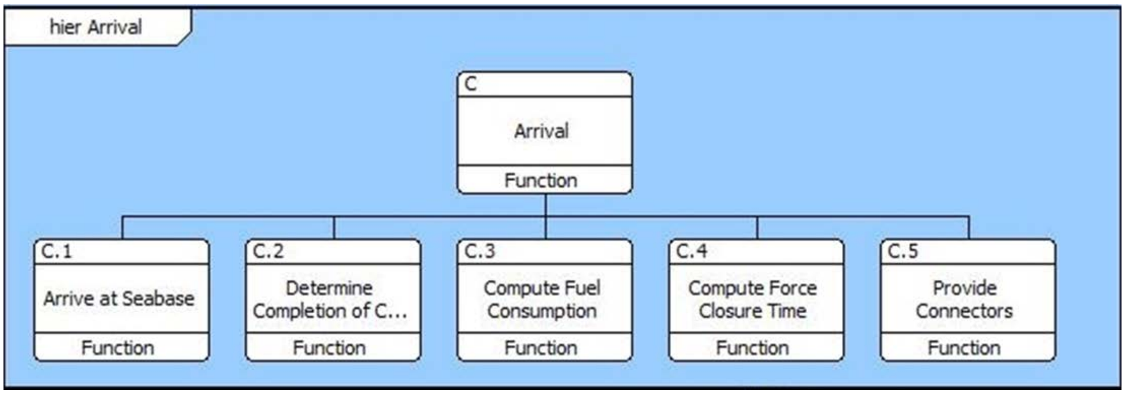


Figure 8. *Arrival* Functional Hierarchy

Enhanced functional flow block diagrams (EFFBD) of the *Planning*, *Marshalling and Movement*, and *Arrival* functions, depicted in Figures 9–11, identify the inputs, outputs, and process logic of the three major functions within the expeditionary transportation system. As depicted in Figure 9, the *Planning* function commences with receipt of the warning order and ends with the publication of the deployment order.

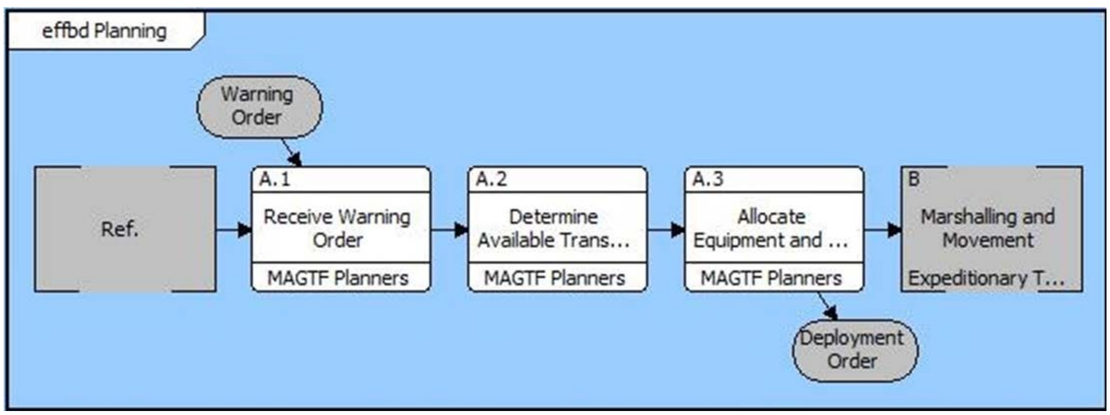


Figure 9. *Planning* EFFBD

Figure 10 represents the parallel functions performed during the *Marshalling and Movement* phase. This demonstrates the possibility that an existing deployment of Marines onboard amphibious shipping could begin transit to the seabase upon execution of the deployment order while other Marine units will embark personnel and equipment upon shipping at an SPOE. Personnel and equipment represent the output of the *Transit to Seabase* function.

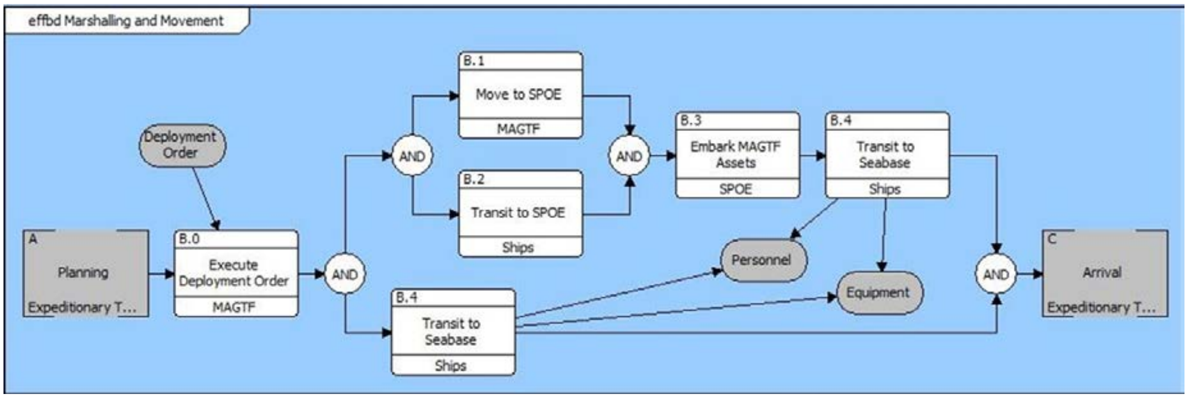


Figure 10. *Marshalling and Movement* EFFBD

Figure 11 represents the arrival of personnel and equipment to the seabase location and the process loop for determining completion of the *Close* phase of the seabasing operation. Upon the completion of force closure, fuel consumption and force closure time are calculated. The connector platforms transported by the various shipping vessels represents the output of the *Arrival* function and transition to the *Assembly* phase of the seabasing operation.

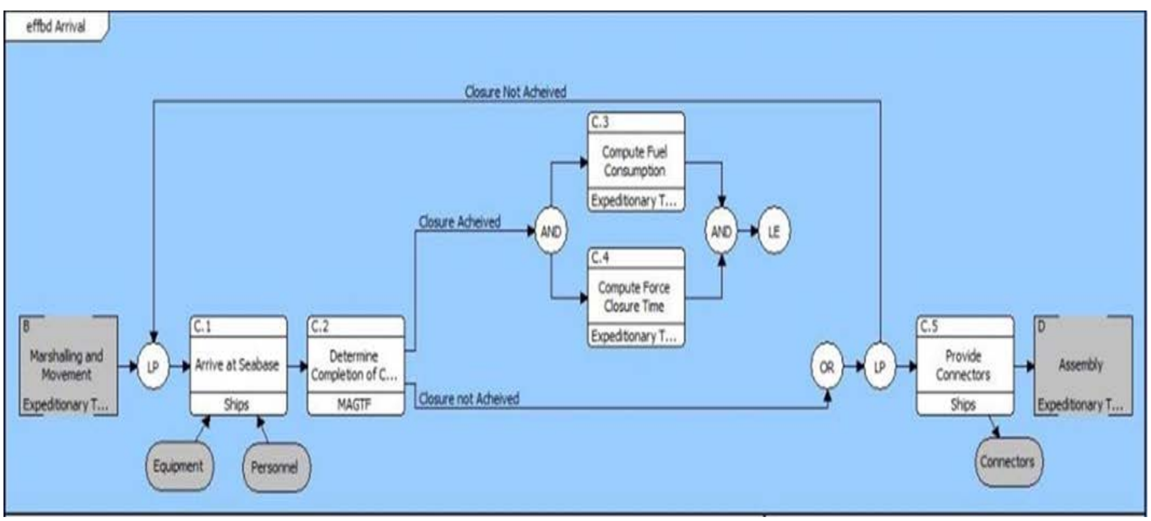


Figure 11. *Arrival* EFFBD

B. PHYSICAL ARCHITECTURE

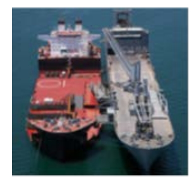
The physical architecture consists of the personnel, equipment, shipping vessels, and SPOE used to perform the functions required in accomplishing the mission within the MARFORPAC area of operations. MEB staff, MARFORPAC planners, and USTRANSCOM planners comprise the personnel required to determine available shipping and the allocation of equipment (e.g., cargo and vehicle capacities) to the available ships. In support of MEB operations, U.S. Navy amphibious shipping consisting of amphibious assault ships (LHDs), dock landing ships (LSDs), and amphibious transport dock ships (LPDs) provide transportation of MEB personnel, equipment, and connector platforms required to support the assigned mission. Table 4 depicts the characteristics and capabilities of U.S. Navy amphibious shipping.

Table 4. Amphibious Shipping Vessel Characteristics. Sources: United States Marine Corps (2014); United States Marine Corps (2015); Petty (2014a); Petty (2014b); Petty (2014c).

Amphibious Shipping			
			
Ship Type	LHD	LSD	LPD
Ship Class	Wasp	Whidbey Island	San Antonio
Speed *(knots)*	22	20	22
Horsepower	70,000	33,000	41,600
Cargo Capacity *(cubic feet)*	125,000	5,000	34,000
Vehicle Capacity *(square feet)*	20,000	12,500	24,000
Connectors			
Transport Aircraft	17	2	4
Landing Craft Air Cushion (LCAC)	3	4	2
Landing Craft Utility (LCU)	2 (in place of LCAC)	3 (in place of LCAC)	1
AAV	61 (in place of LCAC and LCU)	34	14
Fuel Capacity *(gallons)*	536,343	52.160	318,308
Troop Capacity	1687	402	720
Troop Surge	184	102	80

Augmentation of amphibious shipping with prepositioned Military Sealift Command (MSC) container ships (T-AKs) stationed in Guam and Saipan provides the MEB with additional cargo and equipment necessary to support and sustain operations. Additionally, MSC shipping provides seabase-enabling platforms such as the Large, Medium-Speed Roll-on/Roll-off (RO/RO) (LMSR) ship, semi-submersible Mobile Landing Platform (MLP) ship, and cargo container ship (T-AKE). Table 5 depicts the characteristics and capabilities of the MSC shipping.

Table 5. Military Sealift Command Vessel Characteristics—T-AK, T-AKE, LMSR, and MLP. Adapted from United States Marine Corps (2015).

Military Sealift Command Shipping				
				
Ship Type	T-AK	LMSR	T-AKE	MLP
Ship Class	Bobo	Watson	Lewis and Clark	Bobo
Speed *(knots)*	17.7	24	20	15
Horsepower	27,000	64,000	47,874	60,612
Cargo Capacity *(ft^3)*	742,560	378,080	954,000	0
Vehicle Capacity *(ft^2)*	152,000	317,500	0	25,000
Connectors				
Transport Aircraft	0	0	0	0
LCAC	0	0	0	0
LCU	0	0	0	0
AAV	0	0	0	0
Fuel Capacity *(gallons)*	1,430,000	0	1,050,000	380,000
Troop Capacity	96	125	144	96
Troop Surge	0	0	0	0

In considering alternatives to augmenting amphibious shipping and MSC shipping, the capstone team investigated the use of allied nation shipping and commercial shipping platforms to move cargo and personnel to the seabase location. The Australian Navy’s HMAS Canberra class amphibious assault ship provides the capability to

transport cargo, personnel, and vehicles in addition to the ability to launch air and sea connector platforms. With U.S. Navy amphibious shipping concentrated in Japan and San Diego, the Canberra's homeport location of Sydney, Australia provides an amphibious capability in the southwest region of the MARFORPAC area of operations. The Canberra's proximity to the Marine Rotational Force (MRF) – Darwin, Australia provides access to a 2,500-personnel MAGTF (U.S. Marine Corps Forces, Pacific 2015). Table 6 depicts the characteristics and capabilities of the HMAS Canberra.

Table 6. Allied Shipping Vessel Characteristics. Sources: McPhedran (2013); Royal Australian Navy (2010).

Allied Nation Shipping	
	
Ship Type	Amphibious Assault
Ship Class	Canberra
Speed *(knots)*	19
Horsepower	30,000
Cargo Capacity *(ft^3)*	266,560
Vehicle Capacity *(ft^2)*	20,236
Connectors	
Transport Aircraft	18
LCAC	0
LCU	4
AAV	44 (in lieu of LCU)
Fuel Capacity *(gallons)*	673,559
Troop Capacity	1046
Troop Surge	554

Commercial shipping provides another alternative to augment with amphibious shipping. The capstone team, using feedback from the stakeholders, investigated three commercial shipping platforms focused on cargo capacity, connector capacity, and personnel capacity. The Maersk Afloat Forward Staging Base (AFSB), a concept vessel used to support seabasing, provides a reconfigurable platform with large capacities for connectors, personnel, cargo, and vehicles. The U.S. Navy considered retrofitting a Maersk S-Class container ship to support aviation connector platforms and personnel

berthing in addition to its large storage capacity (Naval Research Advisory Committee Panel on Sea Basing 2005). The MV Blue Marlin, a large capacity float-on/float-off (FLO-FLO), shipping platform provided the capability to transport a combination of LCACs and LCUs. Based upon the submersible deck area of the MV Blue Marlin, the capstone team used the dimensions of the LCACs and LCUs to determine the capacity of the MV Blue Marlin to transport these connector platforms. The Norwegian Cruise Liner, Pride of America, provided an alternative means to transport over 2,000 personnel from a SPOE to the seabase location. Upon arrival at the seabase location, personnel transfer from the cruise ship to ships with connector platforms. The HSV Swift, an Australian high-speed amphibious ship, provides the capability to transport personnel and equipment to the seabase location. Given the much smaller capacities of the HSV Swift, the capstone team selected this ship based upon its ability to transport a command element or advance-party to the seabase location. Table 7 depicts the characteristics and capabilities of the commercial shipping alternatives.

Table 7. Commercial Shipping Vessel Characteristics. Sources: Carmel (2004); Naval Research Advisory Committee Panel on Sea Basing (2005); Norwegian Cruise Lines (2015); Todd (2006); Dockwise (2015); Incat Australia Pty Ltd (2013).

Commercial Shipping				
				
Ship Type	AFSB	FLO-FLO	Cruise Liner	HSV
Ship Class	Maersk S Conversion	MV Blue Marlin	Pride of America	Swift
Speed *(knots)*	24.6	14	23	42
Horsepower	75,000	36,207	33,525	38,600
Cargo Capacity *(ft^3)*	266,560	0	0	57,354
Vehicle Capacity *(ft^2)*	90,000	0	0	14,070
Connectors				
Transport Aircraft	69	0	0	3
LCAC	0	14	0	0
LCU	0	15	0	0
AAV	0	0	0	0
Fuel Capacity *(gallons)*	1,000,000	0	0	111,080
Troop Capacity	5,000	0	2,186	250
Troop Surge	0	0	0	0

Factors used in determining the SPOE locations included the homeport of the vessel (e.g., a Naval Base or a commercial port) and the location of Marine Forces in the MARFORPAC area of operations (e.g., a port in Darwin, Australia or Honolulu, Hawaii). The capstone team considered forces already deployed on amphibious vessels (e.g., a deployed MEU) as afloat with no associated SPOE.

C. MEASURES OF EFFECTIVENESS

MOEs quantify the accomplishment of stakeholder provided mission objectives and achievement of desired results. The following objectives were derived from the problem statement and interviews with stakeholders:

- Objective One: Reduce Fuel Consumption
- Objective Two: Reduce Force Closure Time

The objectives help define MOEs and focus on the set of functions for Maritime Prepositioning Force (MPF) operations as depicted in Figure 5;specifically, the *Planning* (A), *Marshaling and Movement* (B), and *Arrival* (C) functions. The MOE's provide a measure used by the team to differentiate the results of the simulation runs. . The following lists the MOE's developed and their corresponding units of measure.

- MOE(1) – Total Fuel Consumption (gallons).
- MOE(2) – Total Time to Close Force at Seabase (hours)

Incorporating different SPOEs in each alternative solution changes the distance ships travel from SPOE to the seabase location, which influences the MOE for each alternative solution. Reducing the distance between SPOE and seabase is a constraint placed upon the MOE that would appear to result in lower fuel consumption and reduced force closure time. However, different ship compositions in an alternative solution and the overall number of ships required to support the defined force closure criteria introduces some variability into the measure. The decision to incorporate different SPOEs also provides MARFORPAC with an additional option of including Marine forces stationed in Hawaii and Australia as part of the force composition instead of relying only on Marine forces deployed from California or Okinawa.

Table 8. MOE(1) Factors Mapped to Functional Hierarchy

MOE(1) TOTAL FUEL CONSUMPTION (GALLONS)	
FACTORS	FACTOR TO FUNCTION MAPPING
Ship Current Speed	B.2, B.4
Distance to Seabase	A.2
Distance to SPOE	A.2
Ship Maximum Horsepower	C.3
Ship Maximum Speed	C.4
Sea State	Environmental

Table 9. MOE(2) Factors Mapped to Functional Hierarchy

MOE(2) TOTAL TIME TO CLOSE FORCE AT SEABASE (HOURS)	
FACTORS	FACTOR TO FUNCTION MAPPING
Ship Speed	B.2, B.4
Distance to Seabase	A.2
Distance to SPOE	A.2
Criteria to Determine Closure	C.2
SPOE Loading Time	B.3
Sea State	Environmental

Tables 8 and 9 lists the factors that influence the MOEs mapped to specific functions within the functional hierarchy described in Chapter IV.A. Ship Maximum Horsepower is unique to MOE(1) and is used to calculate fuel consumption estimates in conjunction with Ship Maximum Speed.. Speed and distance influence MOE(2), which the team expected. SPOE loading time is unique to this MOE and is used to estimate the time to load the vessels at the SPOE prior to transiting to the seabase. A critical factor for MOE(2) is the criteria to determine force closure. This criterion is represented as force closure and is dependent on mission type. Sea state is common to both MOEs and is included to account for the effects of weather on the force's speed.

D. MAPPING THE FUNCTIONAL ARCHITECTURE TO THE PHYSICAL ARCHITECTURE

The physical architecture of the expeditionary transportation system is composed of the organizations, units, and shipping vessels used to perform the *Planning*, *Marshalling and Movement*, and *Arrival* functions. Table 10 depicts a morphological box that maps the functions identified in the functional hierarchy and EFFBDs with the physical elements of the expeditionary transportation system. A key element of the physical architecture is the shipping vessels available for transporting the elements of the MEB to the seabase. Categorization of the shipping vessels as amphibious, Military Sealift Command (MSC), allied nation, and commercial provided a means to distinguish the vessel type capable of performing the functions of the system. For example, amphibious, MSC, allied nation, and commercial shipping can perform the *Transit to*

Seabase function. However, not all commercial and MSC ships are capable of providing organic connector platforms so are not capable of performing the function of *Provide Connectors*.

Table 10. Morphological Box: Mapping Functional Architecture to Physical Architecture

A. Planning	B.0 Execute Deployment Order	B.2 Transit to SPOE	B.3 Embark MAGTF Assets	B.4 Transit to Seabase	C.5 Provide Connectors
MAGTF Planner	MEU	Amphibious • LHD • LSD • LPD	Commercial SPOE	Amphibious • LHD • LSD • LPD	Amphibious • LHD • LSD • LPD
USTRANSCOM	ARG	Allied Nation • Canberra	US Naval Base SPOE	MSC • T-AK • T-AKE • LMSR • MLP	Allied Nation • Canberra
MEB Staff	MEB Staff	Commercial • Cruise Liner • HSV Swift	Afloat	Allied Nation • Canberra	Commercial • MV Blue Marlin • Maersk AFSB • HSV Swift
				Commercial • Cruise Liner • MV Blue Marlin • Maersk AFSB • HSV Swift	

Since the focus of the capstone project is to examine the use of alternative shipping vessels capable of augmenting amphibious shipping in support of Marine Corps amphibious operations, the morphological box provides a visual depiction of alternative shipping vessels and the functions within the system they support.

Using the morphological box, the capstone team developed alternative shipping combinations to support the HA/DR and A2/AD scenarios in order to examine the impact upon fuel consumption and force closure time. Table 11 provides a description of each of the three alternatives for the A2/AD scenario, the type and number of ships used, and the ship's SPOE. The first alternative establishes a baseline of 10 amphibious ships formed from of the aggregation of three MEU's. This alternative relies on using Marine forces

already afloat and from locations within close proxity of the homeports of U.S. Navy amphibious ships in the USPACOM AOR (i.e. Camp Pendleton, CA and Okinawa, Japan). The second alternative incorporates MSC shipping, a commercial cruise liner, and an allied nation amphibious assault ship while reducing the number of amphibious ships by four. The reduction of four amphibious ships originating from San Diego, CA eliminates the longest distance from SPOE to seabase and allows the MAGTF planner to consider deploying Marine forces stationed in Hawaii and Australia where traditional U.S. Navy amphibious ship are not stationed instead of solely from California and Okinawa. The use of commercial and allied nation shipping creates the need for the inclusion of MSC ships to account for the lack of cargo capacity of the commercial cruise liner. The third alternative reduces the amphibious shipping and MSC shipping while incorporating an allied nation amphibious assault ship, and commercial ships consisting of a cruise liner, a Maersk AFSB, and the MV Blue Marlin. The use of the commercial shipping reduces the distance to the seabase in comparison to the other two alternatives while still providing sufficient sealift, Marine forces from Hawaii and Australia, and only requiring support from the MSC's MPF(SE) ships. Figures 12–14 provide graphical depictions of each of the shipping alternatives listed in Table 11 that support the A2/AD scenario described in Chapter III.B.

Table 11. Shipping Alternatives for A2/AD Scenarios

Alternative	Composition of Ships	SPOE	Description
1	Amphibious • LHD x 4 • LSD x 3 • LPD x 3	San Diego, CA Okinawa, JA Afloat	Baseline: All Amphibious
2	Amphibious • LHD x 2 • LSD x 2 • LPD x 2 MSC • T-AK x 3 • T-AKE • LMSR x 2 • MLP Allied Nation • Canberra Commercial • Cruise Liner	Okinawa, JA Guam/Saipan Honolulu, HI Darwin, AU Afloat	Amphibious + MSC with Allied Nation ship and commercial cruise liner
3	Amphibious • LHD x 1 • LSD x 1 • LPD x 1 MSC • T-AKE x 1 • LMSR x 1 • MLP x 1 Allied Nation • Canberra Commercial • Cruise Liner • Maersk AFSB • MV Blue Marlin	Guan/Saipan Honolulu, HI Brisbane, AU Darwin, AU Tanjung Priok, IN Afloat	Amphibious + MPF(SE) with Allied Nation ship and Maersk AFSB concept ship, MV Blue Marlin FLO-FLO, and cruise liner

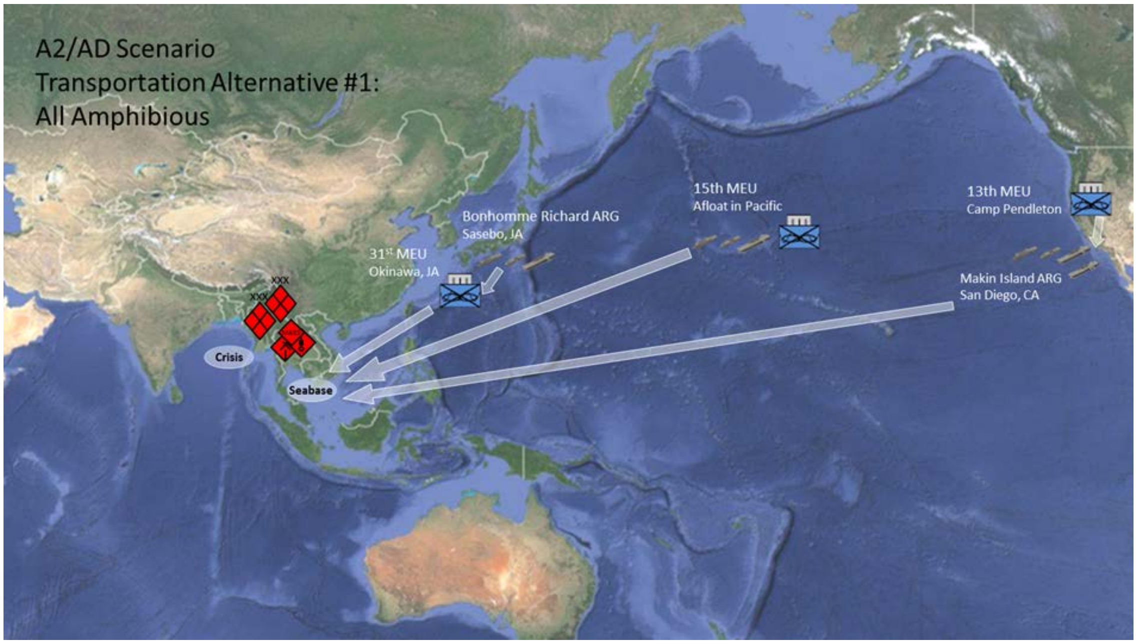


Figure 12. A2/AD Shipping Alternative #1

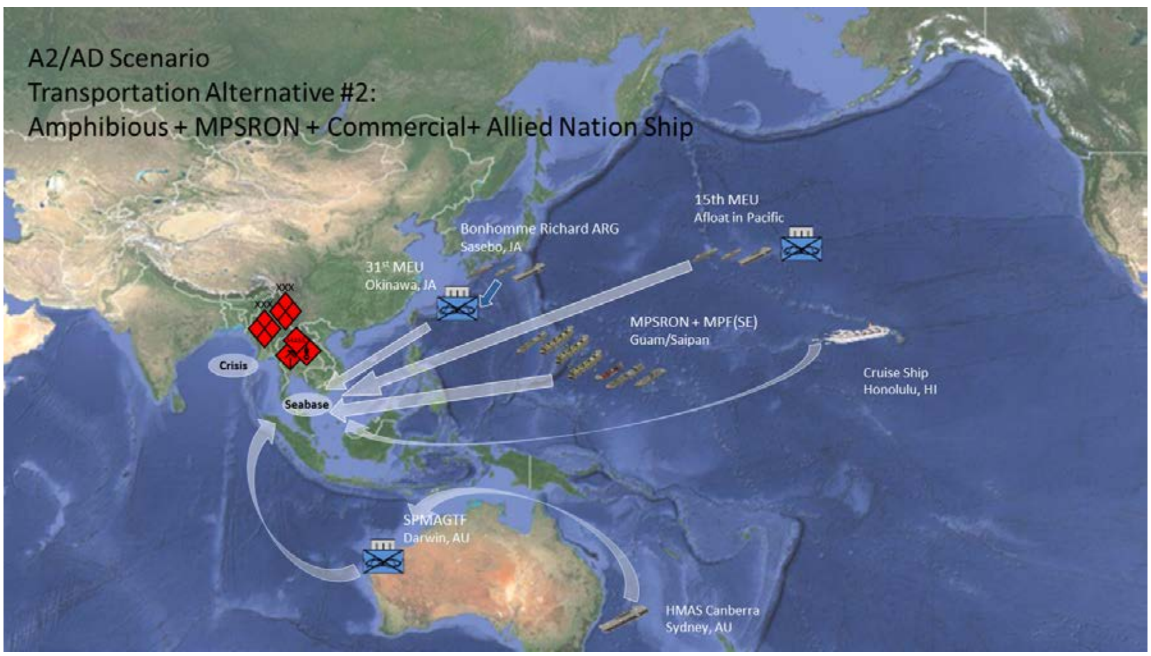


Figure 13. A2/AD Shipping Alternative #2

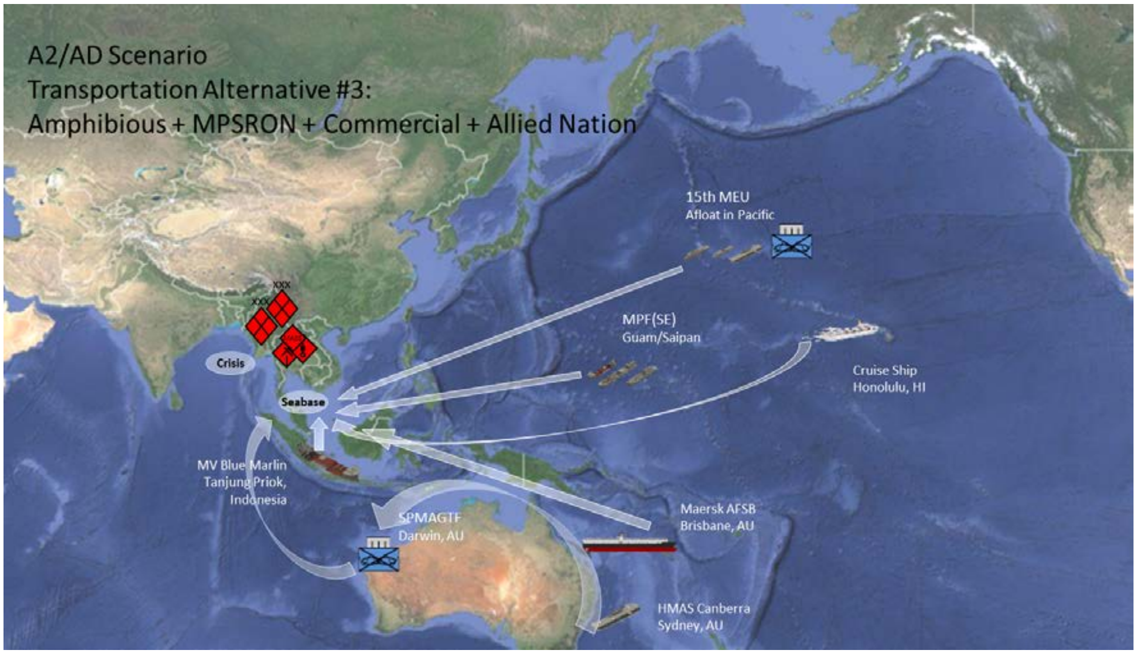


Figure 14. A2/AD Shipping Alternative #3

Since an A2/AD mission involves potential combat operations, the composition of the MEB personnel, equipment, and connectors at the seabase location is essential prior to transitioning to the *Assembly* phase of the operation. For the HA/DR mission, the focus is the arrival of food, water and supplies to the seabase location in order to transition to the *Assembly* phase of the operation. Table 12 provides a description of the shipping combinations to perform the HA/DR operation and the SPOE of the vessels. The first alternative establishes a baseline by using five amphibious ships and three MSC ships. The three MSC ships provide the Maritime Prepositioning Force (MPF) Seabasing-Enabled (SE) package. The second alternative replaces one amphibious ship from Sasebo, JA with a commercial ship, the Maersk AFSB from Brisbane, AU, and incorporates the high-speed vessel HSV Swift from Darwin, AU capable of providing an advance-party to the seabase location.

Table 12. HA/DR Shipping Alternatives

Alternative	Composition of Ships	SPOE	Description
1	Amphibious • LHD x 2 • LSD x 2 • LPD x 1 MSC • T-AKE • LMSR • MLP	Sasebo, JA Guam/Saipan Afloat	Baseline: Amphibious and MPF(SE)
2	Amphibious • LHD x 2 • LSD x 1 • LPD x 1 MSC • T-AKE • LMSR • MLP Commercial • Maersk AFSB • HSV Swift	Sasebo, JA Guam/Saipan Brisbane, AU Darwin, AU Afloat	Baseline (-) with commercial shipping

V. MODELING, SIMULATION, AND ANALYSIS

A. INTRODUCTION

Figure 15 shows the model process description. The team based the process on the Force Deployment Planning and Execution (FDP&E) and Crisis Action Planning (CAP) processes, described in "Marine Corps Order 3000.18" and *Joint Staff Officer's Guide 2000*, respectively, as well as the "MPF-Seabasing Enabled (MPF(SE)) Concept of Employment" and the "Headquarters Marine Corps (HQMC) Prepositioning Program Handbook." The process description was modified from Figure 15 of Paul Beery's thesis, *A Simulation Based Analysis of U.S. Army Watercraft Capabilities in a 2022 Foreign Humanitarian Assistance/Disaster Relief Operation* in which he describes the process for transitioning assets from the staging area to the objective (Beery 2011). Since this capstone report focuses on the seabase, Paul Beery's diagram was used as the foundation from which the model process was developed, modified so that the seabase was the staging area where operations would be conducted. This model focuses strictly on the execution of the warning order up to force closure and the commencement of the *Assembly* phase, where the commencement of the *Assembly* phase denotes follow on efforts outside the scope of the capstone.

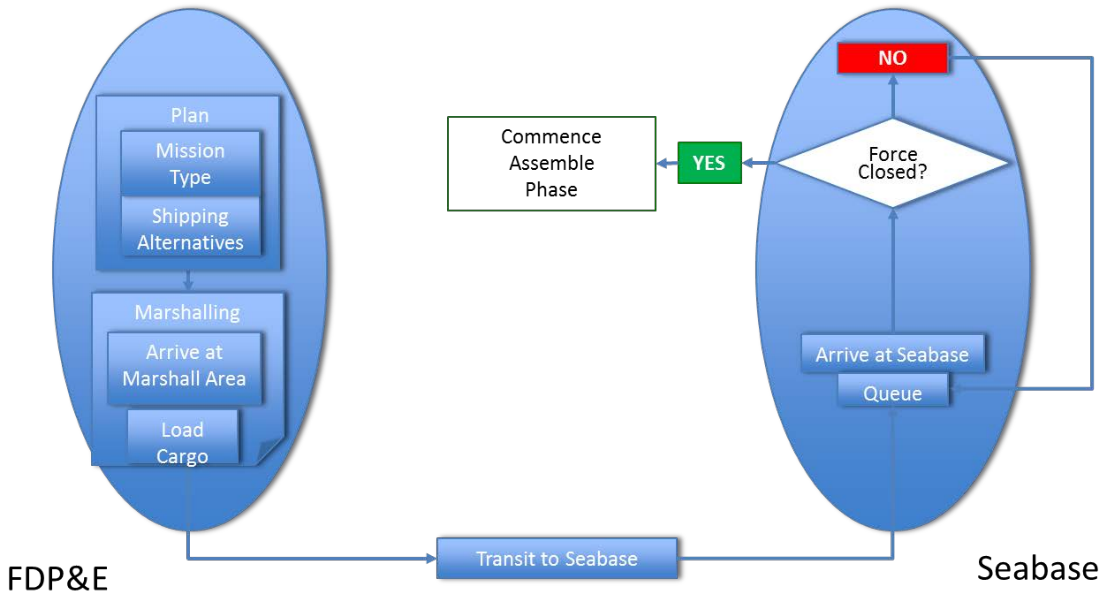


Figure 15. Model Process Description

B. PROCESS STEPS

(1) Plan

Following the determination by the National Command Authorities (NCA) with a WARNORD, the MAGTF Planning Specialists develop the operational plans, as well as the Time-Phased Force and Deployment Data, which details the time phasing of all assets in order to conduct operations. Process includes determining the type of mission and the desired shipping alternatives for operations.

(2) Marshalling

The vessel will transit to the SPOE if cargo needs to be loaded on the vessel. The model will stochastically model the sea state, updating every 12 hours, and determine each ship's transit time to the SPOE. Higher sea state affects time to transit reflected using a multiplier shown in Table 13. Model development was supported by additional research to determine the effects of sea state on ship speed. From the Second International Symposium on Marine Propulsors, the paper "Prediction of Speed Loss of a Ship in Waves" by Chaung and Steen (2011) provided a graph of speed vs. wave height

for a standard tanker. This data was equated to sea state based on wave height and used to approximate sea state influence on vessel speed for all vessels in this study.

Table 13. Speed Multiplier for Transiting Based on Sea State. Adapted from Chaung and Steen (2011).

Sea state	Speed Multiplier for Transiting
0	1.00
1	0.99
2	0.96
3	0.91
4	0.58
5	0.45
6	0.20
7-9	N/A

(3) Load Cargo

The amount of time required to load cargo is described in terms of an average transfer time (ATT). This is based upon data provided in the International Transport Forum "Time Efficiency at World Container Ports" report (Ducruet, Itoh and Merk 2014). This report provided a historical measurement of ATT for ports based on geographic location. Our scenarios are based in the Oceania region thus the ATT used is described by the following statistics for Oceania:

- average = 1.538 days
- standard Deviation = 2.127 days
- coefficient of Variation = 1.383 days
- max = 16.667 days

(4) Transit to Seabase

The model stochastically models the sea state, updating every 12 hours, and determine each ship's transit time to the seabase. Higher sea state affects time to transit reflected using a multiplier shown in Table 13.

(5) Arrive at Seabase

The model determines if the ships have arrived at the seabase location.

(6) Force Closed

The model will write the force closure time and end the simulation once the required quantities arrive. This constitutes the arrival of an 80% MEB equipment density list at the seabase location for A2/AD or if the minimum required food, water, and supplies have been received for HA/DR.

(7) Commence *Assembly* Phase

Upon establishing force closure, the model will calculate the total fuel consumed for all vessels that have arrived at the seabase location. Fuel consumption equations were derived from the report "Calculating Fuel Consumption" (Becker 2000) and *Reed's Naval Architecture for Marine Engineers* (Stokoe 2003, 130). The Becker article provided a method to compute maximum fuel consumption based on fuel specific weight (*FSW*), specific fuel consumption (*SFC*) and horsepower, shown in Table 14, knowing maximum horsepower (HP_{max}). Using the ratio of fuel consumption to speed presented by Stokoe (2003) yields the following equations:

- *GPHmax* = (*SFC* x *HPmax*) / *FSW*
- *cons1*= current fuel consumption at current velocity = *GHPmax*
- *cons2*= computed fuel consumption at new velocity
- *V1* = new velocity
- *V2* = speed at max horsepower
- $$\frac{cons1}{cons2} = \left(\frac{V1}{V2}\right)^3$$
- *cons2*= (*GPHmax* x $V1^3$) / $V2^3$ (*GPH*)

Table 14. Max Fuel Consumption in Gallons per Hour (GPH). Adapted from Becker (2000).

Constants Gas Diesel	Gas (lb/hp)	Diesel (lb/hp)
SFC	0.5	0.4
FSW	6.1	7.2

C. MODEL RESULTS

1. Analysis of Variance

The capstone team designed a simulation model for each alternative solution using ExtendSim simulation software. The simulations ran 100 times for each scenario to collect enough data to perform a statistical analysis on the results. Table 15 below is a list of the data output collected from the simulations. Additional data was output by each simulation run to verify the force closure requirements were met as described in step 6 of the model process detailed in Section B above.

Table 15. Simulation Data Output

Force Closure Time (*hours*)	Total Fuel of All Ships (*gallons*)	Total Fuel at Force Closure (*gallons*)	Average Sea State (*0-9*)	Average Speed (*knots*)	Average Distance Travelled at Force Closure (*NM*)	Number of Ships at Force Closure	Average Horsepower at Force Closure (*hp*)

The data generated by the simulations was tabulated in a Microsoft Excel spreadsheet. In addition, to simplify the scenario number and type of mission represented, the team utilized a number designation after the specific mission type. For example, A2/AD1 would denote an A2/AD mission for scenario 1. The capstone team then conducted an Analysis of Variance (ANOVA) test on the simulation results to determine which factors contributed to the Force Closure Time, and Total Fuel at Force Closure for each scenario. Two separate regression analyses were performed, treating Force Closure Time

and Total Fuel at Force Closure as dependent variables, and using Average Sea state, Speed, Distance, Average Horsepower, Number of Ships, and either Force Closure time or Total Fuel at Force Closure (depending on the analysis), as independent variables. The results from the regression analysis showed which independent variable influenced the outcome of the dependent variable, and which variables had no statistical significance on the outcome. An initial regression analysis was performed to determine which variables were significant, and then an additional analysis was run, omitting the non-influential variables, in order to generate coefficients for a prediction equation. Figure 16 shows a sample of the final regression analysis results of Fuel at Force Closure for A2/AD1.

SUMMARY OUTPUT					
Regression Statistics					
Multiple R	0.99061109				
R Square	0.98131034				
Adjusted R Square	0.98092499				
Standard Error	83868.7438				
Observations	100				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	3.58242E+13	1.79121E+13	2546.517712	1.48822E-84
Residual	97	6.82295E+11	7033966183		
Total	99	3.65065E+13			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-3190292.7	103142.3079	-30.93098001	4.83177E-52	-3395001.594
Avg Seastate	-156382.83	27607.60694	-5.664483299	1.50679E-07	-211176.2861
# Ships @ FC	1017331.54	14445.12665	70.42731905	4.27706E-85	988661.9655

Figure 16. A2/AD1 Fuel at Force Closure Regression Analysis Results

The regression statistics for this analysis shows a high R2 value (0.98), indicating that the predicted output of the statistical model fits the data well. Examining the P-values from the ANOVA test shows that the parameters tested have a correlation to the output of the model; therefore, the coefficients provided by the analysis can be used to

form a surrogate model of the Fuel at Force Closure based on the number of ships and sea state during travel.

Tables 16 and 17 summarize the relevant parameters identified by the regression analysis for Fuel at Force Closure and Force Closure Time for each scenario. These tables show that in general, sea state and the number of ships have the greatest effect on fuel consumption for the mission models. Likewise, speed and distance have the greatest effect on the time to force closure for the mission models.

Table 16. Fuel at Force Closure Contributors

	Average Speed (*knots*)	Average Distance Travelled of each Ship at Force Closure	Average Sea state	Number of Ships at Force Closure	Average hp at Force Closure
A2/AD 1			X	X	
A2/AD 2			X	X	
A2/AD 3		X	X	X	
HA/DR 1			X	X	X
HA/DR 2		X		X	X

Table 17. Force Closure Time Contributors

	Average Speed (*knots*)	Average Distance Travelled of each Ship at Force Closure	Average Sea state	Number of Ships at Force Closure	Average hp at Force Closure
A2/AD 1	X	X			
A2/AD 2	X	X			X
A2/AD 3	X	X			
HA/DR 1	X	X	X		
HA/DR 2	X	X			

A comparison of the results from the simulation shows which alternative solutions within each mission type (i.e. A2/AD and HA/DR) produce the most desirable results based on the MOEs established for the study. Figure 17 shows a comparison of the fuel consumed versus force closure time for the A2/AD mission profiles. The A2/AD3 alternative solution shows a significant reduction in fuel usage as well as being the fastest to achieve force closure. Figure 18 shows the comparison for the HA/DR missions and demonstrates that the HA/DR1 alternative solution used less fuel, but was not significantly faster than the HA/DR2 alternative solution making HA/DR1 more fuel-efficient.

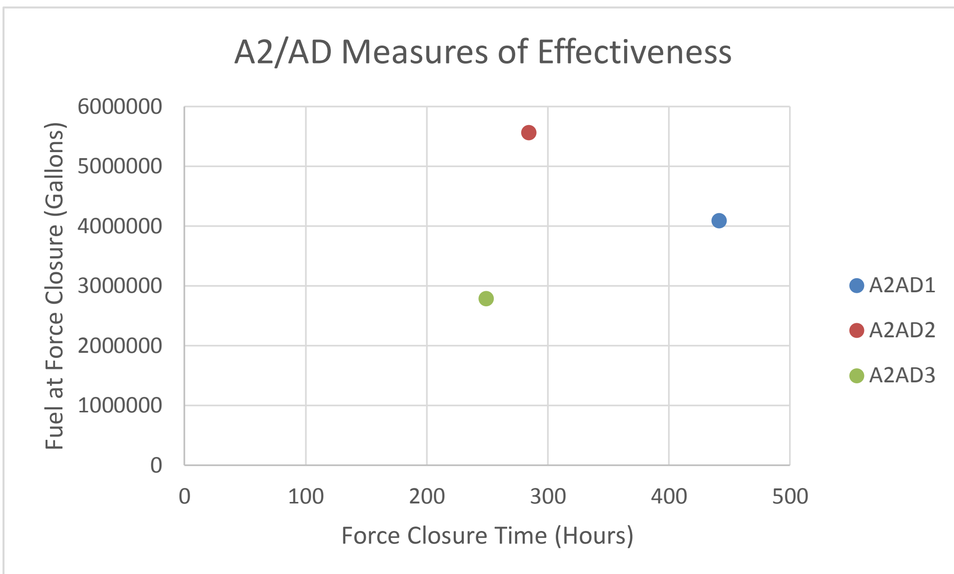


Figure 17. A2/AD MOE Comparison

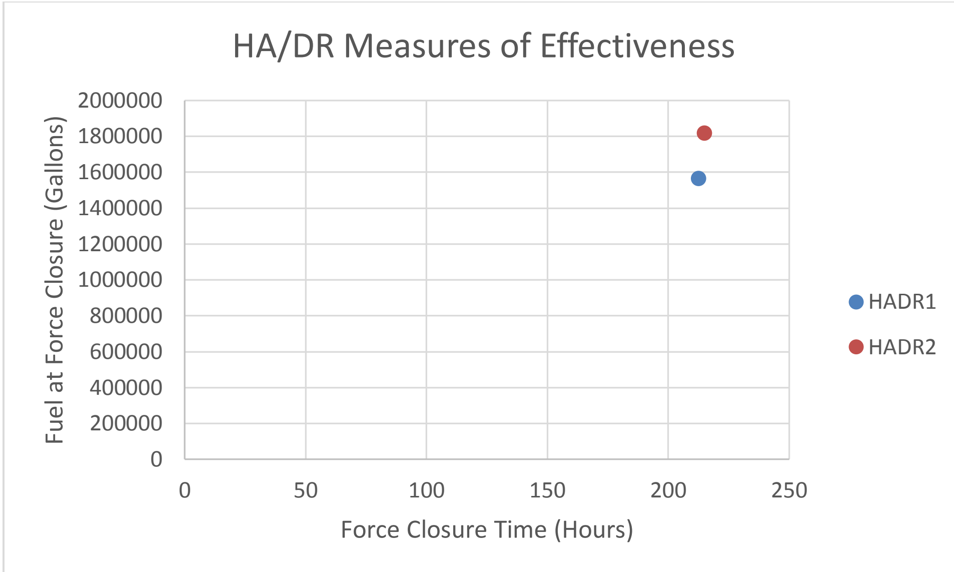


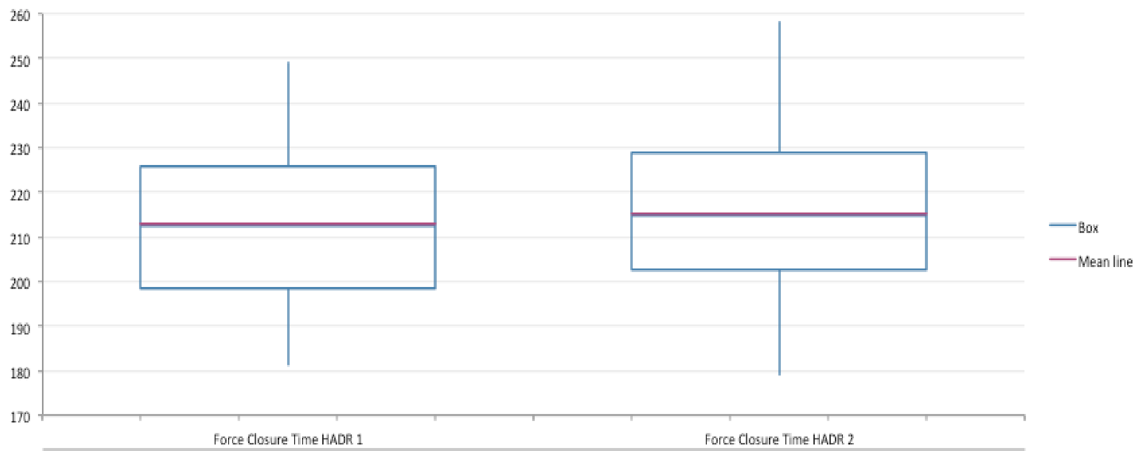
Figure 18. HA/DR MOE Comparison

2. Boxplot Analysis

A boxplot is a graph providing a visual summary of the distribution of a variable. It represents a five-number summary of the variable listing the minimum, maximum, upper and lower quartile and median. The red line is the sample mean and the blue the median. The boxplots presented are Tukey boxplots where the whiskers, variability outside the upper and lower quartile, represent 1.5 of the interquartile range. This shows the spread or variability of the variable. Outliers identified as extreme indicate an anomaly in the data warranting further investigation.

a. HA/DR Force Closure Time

Figure 19 provides a comparison of the Force Closure Times for the HA/DR datasets. Examination of the means for the datasets shows minor variation leading to the conclusion that there is no statistical significance between the means of the datasets. Thus, one cannot conclude that dataset HA/DR1 is different from HA/DR2 and augmenting the force with commercial shipping will not significantly influence force closure time.

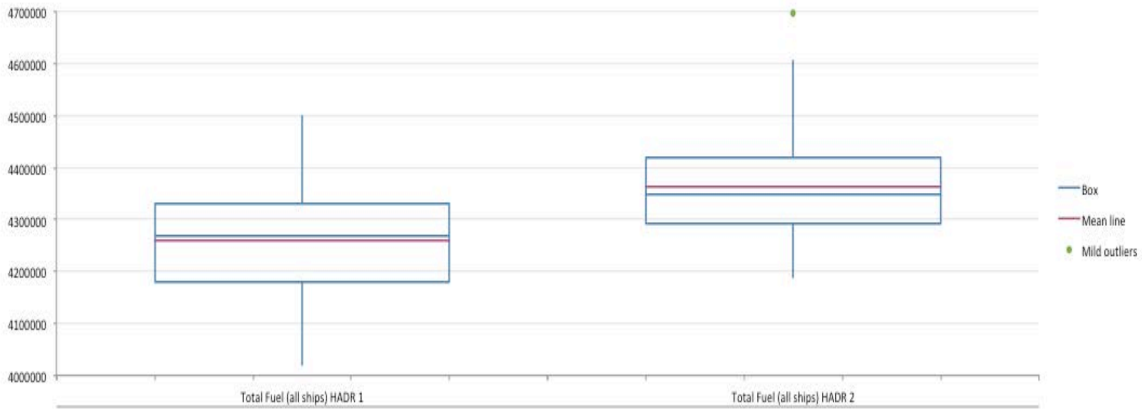


Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Force Closure Time HADR 1	100	212.71832	181.34667	181.34667	198.48412	212.54189	225.82739	249.03896	249.03896
Force Closure Time HADR 2	100	215.07927	179.20275	179.20275	202.52482	214.61602	228.85275	257.9904	257.9904

Figure 19. HA/DR Force Closure Time

b. HA/DR Total Fuel

Figure 20 provides a comparison of the Total Fuel consumed for the HA/DR datasets. Examination of the means for the datasets shows sufficient variation leading to the conclusion that there is statistical significance between the means of the datasets. Thus, one can conclude that dataset HA/DR1 is different from HA/DR2 and that total fuel consumed time is effected by augmentation with commercial shipping. In this case, it is a negative effect where the augmented shipping package consumed on average an additional 1% more fuel. HA/DR1 contains a mild outlier caused when the shipping package achieved force closure with six ships versus the mean of three. Low capacity shipping arriving at the seabase produced this outlier. The MLP USS John Glen has zero cargo capacity and therefore does not contribute to force closure for the HA/DR mission.

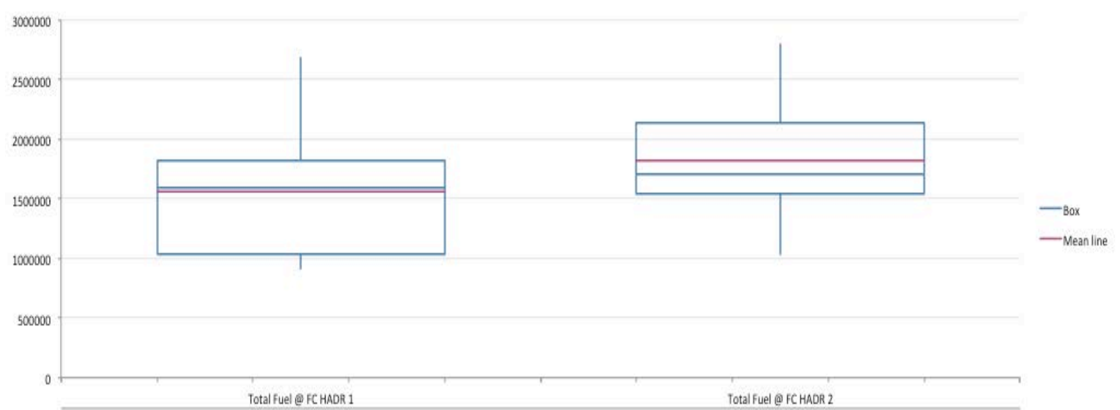


Variable	*Count*	*Mean*	*Minimum*	*Lower whisker*	*Q1*	*Median*	*Q3*	*Upper whisker*	*Maximum*
Total Fuel (all ships) HADR 1	100	4,258,750.68336	4,019,333.93277	4,019,333.93277	4,179,386.54314	4,269,119.87325	4,331,461.7188	4,497,910.45369	4,497,910.45369
Total Fuel (all ships) HADR 2	100	4,364,376.13381	4,187,456.62791	4,187,456.62791	4,292,947.34761	4,348,093.52261	4,419,956.12451	4,606,141.61569	4,696,193.49173

Figure 20. HA/DR Total Fuel

c. HA/DR Total Fuel at Force Closure

Figure 21 provides a comparison of the total fuel consumed at force closure for the HA/DR datasets. Examination of the means for the datasets shows sufficient variation leading to the conclusion that there is statistical significance between the means of the datasets. Therefore, HA/DR1 is different from HA/DR2 and augmenting the force with commercial shipping affects total fuel at force closure. In this case, it is a negative effect where the augmented shipping package consumed on average an additional 8% more fuel.

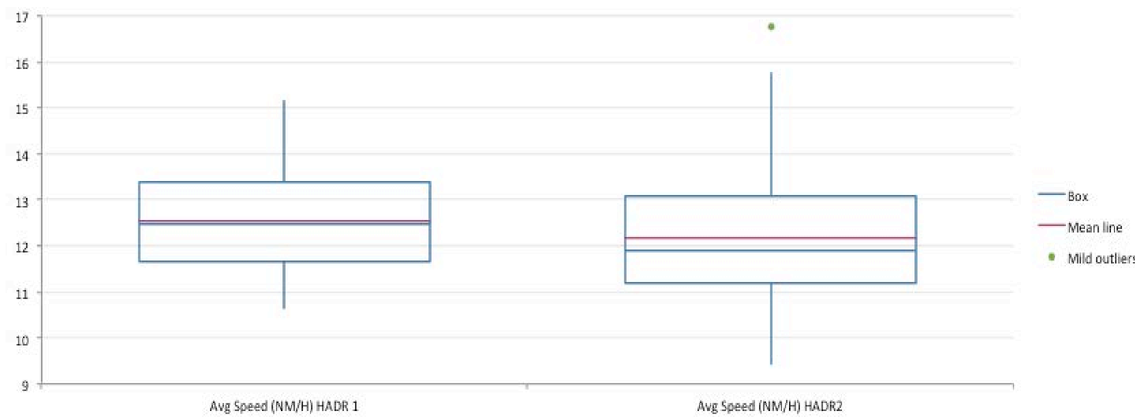


Variable	*Count*	*Mean*	*Minimum*	*Lower whisker*	*Q1*	*Median*	*Q3*	*Upper whisker*	*Maximum*
Total Fuel @ FC HADR 1	100	1,562,379.35041	916,069.1643	916,069.1643	1,032,481.24976	1,588,752.08184	1,820,689.21877	2,679,541.14468	2,679,541.14468
Total Fuel @ FC HADR 2	100	1,816,246.30817	1,031,087.90311	1,031,087.90311	1,544,004.55387	1,712,199.47643	2,133,985.50436	2,793,522.54785	2,793,522.54785

Figure 21. HA/DR Total Fuel at Force Closure

d. HA/DR Average Speed

Figure 22 provides a comparison of the average speed for the HA/DR datasets. Examination of the means for the datasets shows insufficient variation leading to the conclusion that there is no statistical significance between the means of the datasets. The datasets do not statistically show that augmenting the force with commercial shipping does not affect average speed. HA/DR1 contains a mild outlier caused when the shipping package achieved force closure with six ships versus the mean of three. Low capacity shipping arriving at the seabase produced this outlier. The MLP USS John Glen has zero cargo capacity. Therefore, it does not contribute to force closure for the HA/DR mission.



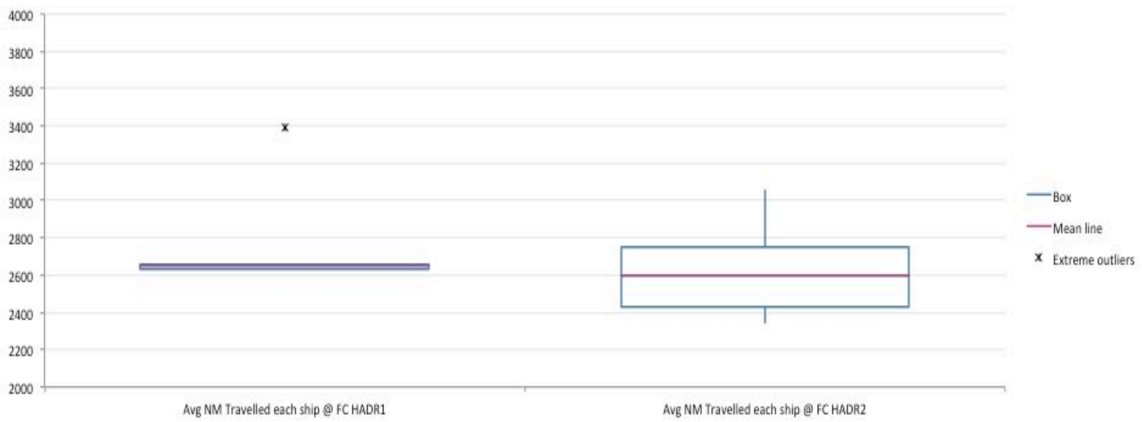
Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Avg Speed (NM/H) HADR 1	100	12.54743	10.65616	10.65616	11.67758	12.46671	13.39823	15.12631	15.12631
Avg Speed (NM/H) HADR2	100	12.1749	9.43966	9.43966	11.18532	11.90934	13.07858	15.745	16.76434

Figure 22. HA/DR Average Speed

e. HA/DR Average Distance Traveled

Figure 23 provides a comparison of the average distance traveled for the HA/DR datasets. Examination of the means for the datasets shows insufficient variation leading to the conclusion that there is no statistical significance between the means of the datasets. The datasets do not statistically indicate that augmenting the force with commercial shipping will effect average distance traveled. Thus, one can conclude that dataset HA/DR1 is not different from HA/DR2. HA/DR1 contains an outlier attributed to the shipping package achieving force closure with six ships versus the mean of three. Low capacity shipping arriving at the seabase produced this outlier. The MLP USS John

Glen has zero cargo capacity. Therefore, it does not contribute to force closure for the HA/DR mission.

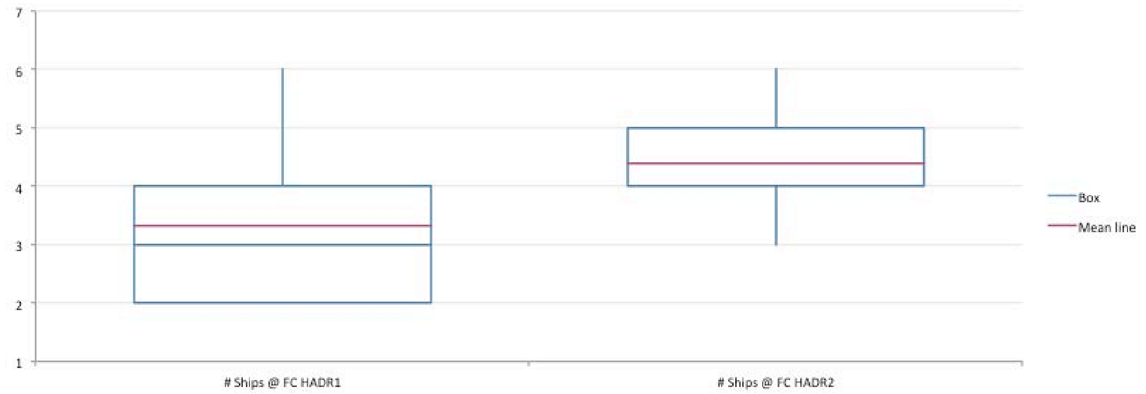


Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Avg NM Travelled each ship @ FC HADR1	100	2,653.02467	2,632.	2,632.	2,632.	2,632.	2,661.5	2,661.5	3,395.16667
Avg NM Travelled each ship @ FC HADR2	100	2,599.11833	2,343.66667	2,343.66667	2,430.5	2,602.4	2,754.4	3,051.8	3,051.8

Figure 23. HA/DR Average Distance Traveled

f. HA/DR Number of Ships at Force Closure

Figure 24 provides a comparison of the number of ships at force closure for the HA/DR datasets. Examination of the means for the datasets shows sufficient variation leading to the conclusion that there is statistical significance between the means of the datasets. The HA/DR1 dataset is different from HA/DR2. Therefore, the total number of ships at force closure affects the force. In this case, it is a positive effect where the augmented shipping package increased on average an additional 14% in the number of ships needed for force closure.

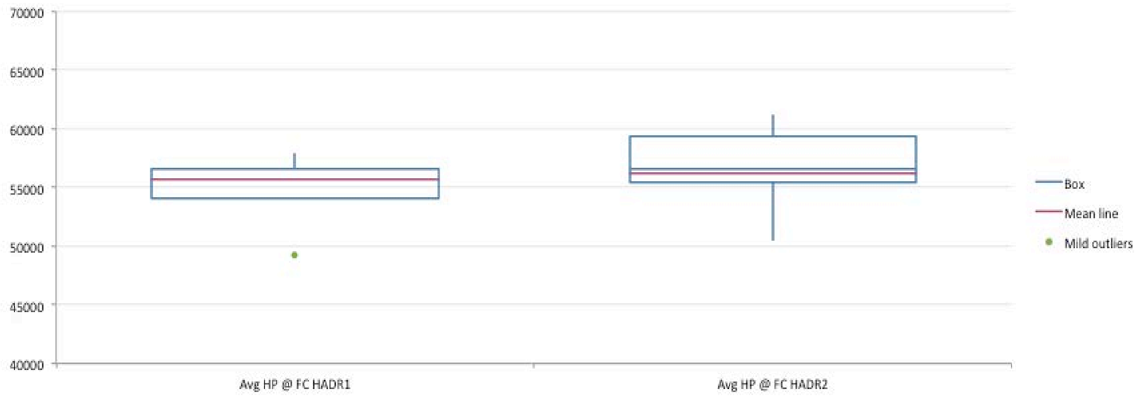


Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
# Ships @ FC HADR1	100	3.33	2.	2.	2.	3.	4.	6.	6.
# Ships @ FC HADR2	100	4.4	3.	3.	4.	4.	5.	6.	6.

Figure 24. HA/DR Number of Ships at Force Closure

g. HA/DR Average Horsepower

Figure 25 provides a comparison of the average horsepower for the HA/DR datasets. Examination of the means for the datasets shows insufficient variation leading to the conclusion that there is no statistical significance between the means of the datasets. Thus, there is insufficient evidence to suggest that average horsepower is affected by augmentation with commercial shipping. HA/DR1 contains a mild outlier caused when the shipping package achieved force closure with six ships versus the mean of three. Low capacity shipping arriving at the seabase produced this outlier. The MLP USS John Glen has zero cargo capacity. Therefore, it does not contribute to force closure for the HA/DR mission.

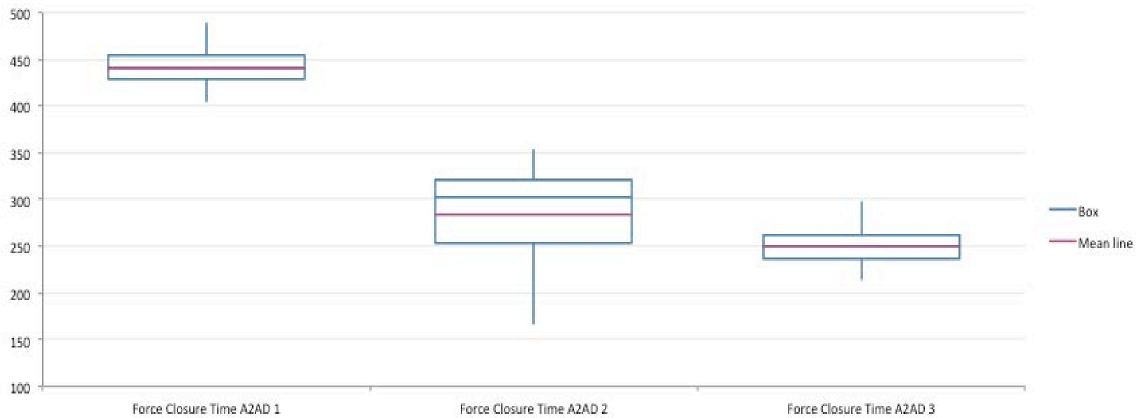


Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Avg HP @ FC HADR1	100	55,684.89767	49,245.66667	54,008.5	54,008.5	56,517.	56,517.	57,882.	57,882.
Avg HP @ FC HADR2	100	56,219.56233	50,544.66667	50,544.66667	55,408.5	56,533.85	59,326.8	61,105.66667	61,105.66667

Figure 25. HA/DR Average Horsepower

h. A2/AD Force Closure Time

Figure 26 provides a comparison of the force closure time for the A2/AD datasets. Examination of the means for the datasets shows sufficient variation leading to the conclusion that there is statistical significance between the datasets. Thus, one can conclude that the A2/AD datasets are different. Augmenting the force with commercial shipping will affect force closure time, with an obvious reason being the related change in the overall distance traveled to deliver the forces to the seabase. In this case, it is a negative effect where the augmented shipping package reduced the mean force closure by 20%.

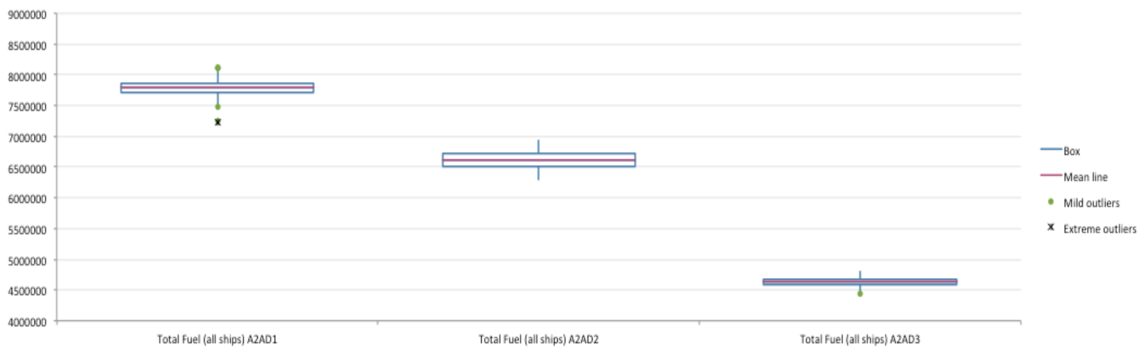


Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Force Closure Time A2AD 1	100	441.64212	404.89011	404.89011	428.49701	440.97259	453.88285	487.96603	487.96603
Force Closure Time A2AD 2	100	284.69718	166.64838	166.64838	253.60821	302.05596	320.53665	353.86695	353.86695
Force Closure Time A2AD 3	100	249.57846	213.84848	213.84848	236.74516	250.08999	261.79392	296.54099	296.54099

Figure 26. A2/AD Force Closure Time

i. A2/AD Total Fuel

Figure 27 provides a comparison of the total fuel consumed for the A2/AD datasets. Examination of the means for the datasets shows sufficient variation leading to the conclusion that there is statistical significance between the datasets. The A2/AD datasets are different. Augmenting the force with commercial vessels does affect total fuel consumed, again due at least in part to the resultant change in distance traveled to the seabase. In this case, a negative effect shows that the augmented shipping package reduced total fuel by 15%. Utilizing fewer larger capacity ships in favor of smaller capacity ships results in reduced total fuel consumed. A2/AD1 dataset consists of naval amphibious ships with higher speed but lower capacity. Thus, more ships will consume more total fuel. Augmentation of the A2/AD3 dataset with the Maersk AFSB provides a ship is capable of delivering the majority of the MEB EDL in one trip.



Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Total Fuel (all ships) A2AD1	100	7,787,070.31595	7,217,150.44813	7,521,072.1538	7,710,466.24011	7,796,052.86646	7,866,478.24148	8,078,874.26853	8,118,611.00112
Total Fuel (all ships) A2AD2	100	6,621,135.73422	6,295,420.32269	6,295,420.32269	6,509,572.40154	6,609,535.86644	6,726,745.22448	6,923,600.98451	6,923,600.98451
Total Fuel (all ships) A2AD3	100	4,639,439.3781	4,440,595.11223	4,457,821.6152	4,590,402.00962	4,641,125.75998	4,681,910.79968	4,797,221.46457	4,797,221.46457

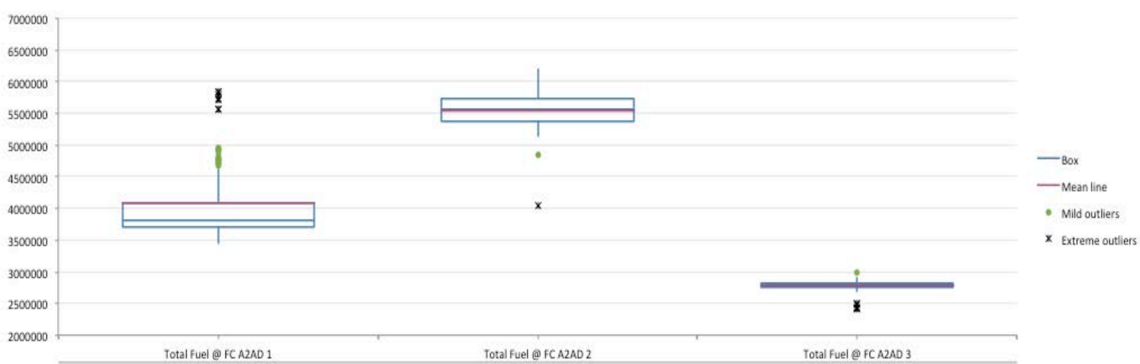
Figure 27. A2/AD Total Fuel

j. A2/AD Total Fuel at Force Closure

Figure 28 provides a comparison of the total fuel consumed at force closure time for the A2/AD datasets. Examination of the means for the datasets shows sufficient variation leading to the conclusion that there is statistical significance between the datasets. The A2/AD dataset's are different. The force's total fuel at force closure is affected by augmentation of commercial shipping. In this case, the augmented shipping package reduced mean total fuel consumption at force closure by 22%. In A2/AD1, the ship package comprised of naval amphibious vessels, achieved the second lowest total fuel consumed at force closure. This dataset had the highest average max speed of 21.4 knots but had the lowest twenty-foot equivalent unit (TEU) capacity at 45. In A2/AD2, the ship package comprised of naval amphibious vessels and augmented with a commercial cruise ship and allied nation assault amphibious vessel consumed the most fuel to force closure. This ship package had an average max speed of 20 knots and a capacity of 220 TEUs. This was the slowest average max speed and largest capacity for the A2/AD datasets. Comparing the results from A2/AD1 and A2/AD2 indicates that if reducing fuel consumption is the objective, then one should select vessel speed over capacity. A2/AD3 resulted in the least fuel consumed at force closure. A2/AD3 had a mean max speed of 20 and an average cargo capacity of 148 TEUs. This ship package consisted of MPSRON, ARG and augmentation with cruise ship, Maersk AFSB, HMAS Canberra amphibious vessel and MV Blue Marlin Flo-Flo. The addition of the Maersk

was a game changer. It was capable of traveling at 25 knots, had a capacity of 180 TEU and had a 90,000 square feet vehicle capacity. Force closure was routinely achieved by the arrival of the Maersk at the seabase. Adding a fast ship with high capacity reduces the total fuel consumed to achieve force closure.

This factor has a number of outliers. A2/AD1 achieves force closure with nine ships. The number of ships at force closure boxplot, Figure 31, shows this the maximum number for this dataset. This is an indication that the lower capacity amphibious transport and dock ships arrived before the larger capacity assault ships. A2/AD2 has a single extreme outlier. This is a situation where 10 ships achieve force closure. The number of ships at force closure boxplot, Figure 31, shows this the minimum number for this dataset. This is an indication that the larger capacity vessels such as the HMAS Canberra and MPSRON ships arrived at the seabase before lower capacity ships achieving force closure. A2/AD3 outlier is the effect of augmenting the force with the Maersk AFSB and is a result of the Maersk capability to carry the majority of the MEB EDL cargo.



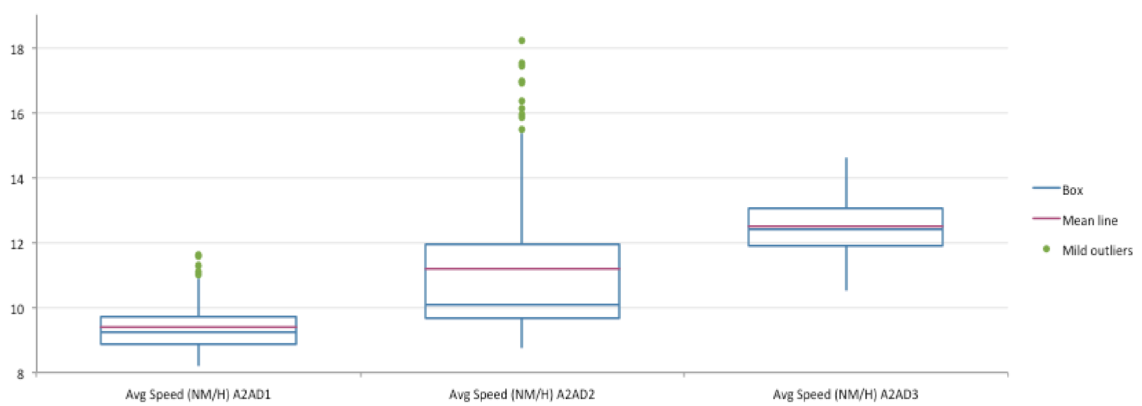
Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Total Fuel @ FC A2AD 1	100	4,082,989.29378	3,455,914.04707	3,455,914.04707	3,714,447.11368	3,809,892.68348	4,086,033.69054	4,606,718.55232	5,845,619.10523
Total Fuel @ FC A2AD 2	100	5,551,448.67435	4,044,347.47568	5,137,297.94109	5,382,420.0949	5,558,952.96123	5,736,867.5762	6,205,478.11468	6,205,478.11468
Total Fuel @ FC A2AD 3	100	2,782,151.31676	2,419,627.65431	2,686,874.73806	2,766,659.62602	2,800,000.00525	2,828,999.39401	2,906,659.9456	2,988,702.11894

Figure 28. A2/AD Total Fuel at Force Closure

k. A2/AD Average Speed

Figure 29 provides a comparison of the average speed for the A2/AD datasets. Examination of the means for the datasets shows sufficient variation leading to the conclusion that there is statistical significance between the datasets. The A2/AD datasets

are different and that augmentation with commercial shipping affects the average speed of the force. Augmenting shipping packages increased mean average speed by 9%. A2/AD1 ship package achieved the slowest mean speed. This dataset has the highest average max speed of 21.4 knots but had the lowest TEU capacity at 45. The low mean speed is a result of the aggregate effect of the ship's speed in the model when transiting an aggregate from SPOE to 12 hours before arriving at the seabase. A2/AD2, the ship package comprised of naval amphibious vessels and augmented with a commercial cruise ship and allied nation assault amphibious vessel had the second highest mean speed. This ship package has an average max speed of 20 knots and a capacity of 220 TEUs. This was the slowest average max speed and largest capacity for the A2/AD datasets. Higher mean speeds were a result of higher capacity ships arriving at the seabase and achieving force closure. A2/AD3 resulted in the least fuel consumed at force closure. A2/AD3 ship package had a mean max speed of 20 knots and an average cargo capacity of 148 TEUs. This ship package consisted of MPSRON, ARG and augmentation with cruise ship, Maersk AFSB, HMAS Canberra amphibious vessel and MV Blue Marlin FLO-FLO. The addition of the Maersk provided a capability of traveling at 25 knots while transporting 180 TEU and had a 90,000 square feet vehicle capacity. Adding a fast ship with high capacity increases the average speed to force closure.

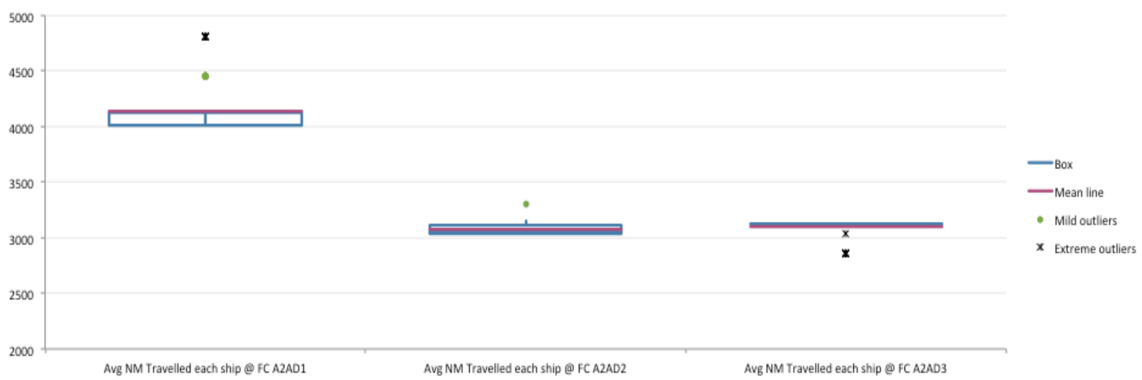


Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Avg Speed (NM/H) A2AD1	100	9.40707	8.21222	8.21222	8.89217	9.23045	9.71245	10.88711	11.59615
Avg Speed (NM/H) A2AD2	100	11.17871	8.79245	8.79245	9.67013	10.10584	11.96274	15.31977	18.20507
Avg Speed (NM/H) A2AD3	100	12.49233	10.52998	10.52998	11.89085	12.40628	13.04403	14.60179	14.60179

Figure 29. A2/AD Average Speed

l. A2/AD Average Distance Traveled

Figure 30 provides a comparison of the average distance traveled for the A2/AD datasets. Examination of the means for the datasets shows sufficient variation leading to the conclusion that there is statistical significance between the datasets. Thus, one can conclude that the A2/AD datasets are different and distances from the SPOE to the seabase affect that average distance traveled.



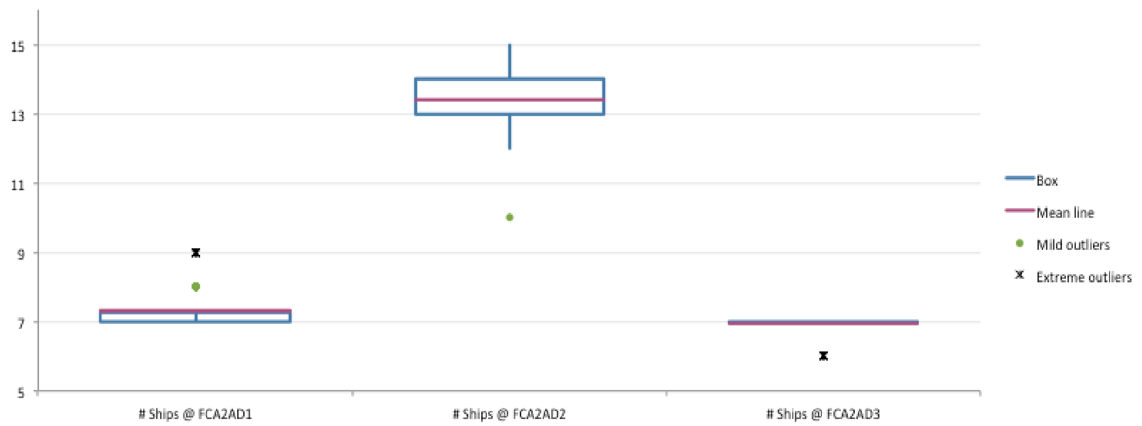
Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Avg NM Travelled each ship @ FC A2AD1	100	4,144.80762	4,007.28571	4,007.28571	4,007.28571	4,007.28571	4,120.21429	4,007.28571	4,810.33333
Avg NM Travelled each ship @ FC A2AD2	100	3,075.53645	3,033.84615	3,033.84615	3,033.84615	3,048.13141	3,111.35714	3,154.4	3,298.
Avg NM Travelled each ship @ FC A2AD3	100	3,105.91	2,858.83333	3,122.57143	3,122.57143	3,122.57143	3,122.57143	3,122.57143	3,122.57143

Figure 30. A2/AD Average Distance Traveled

m. A2/AD Number of Ships at Force Closure

Figure 31 provides a comparison of the number of ships needed to achieve force closure for the A2/AD datasets. Examination of the means for the datasets shows sufficient variation leading to the conclusion that there is statistical significance between the datasets. The A2/AD datasets are different. Augmenting the force with commercial shipping impact the number of ships needed to achieve force closure. A2/AD1 represents the standard MEB ARG. A2/AD2 is the ARG augmented with a cruise liner and nation allied nation amphibious vessel. This dataset has the highest number of ships reaching force closure due to the inclusion of the USNS John Glenn and the Pride of America. Both ships do not contribute to meeting force closure cargo requirements and therefore increase the ship count. A2/AD3 has the lowest ship count caused by augmenting the

ARG with the Maersk AFSB. The capacity of this ship enables rapid achievement of force closure.

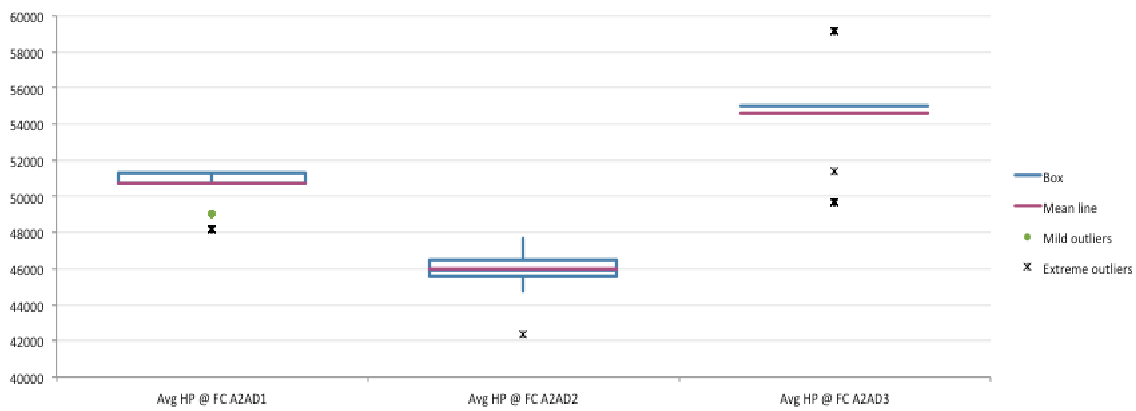


Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
# Ships @ FCA2AD1	100	7.32	7.	7.	7.	7.	7.25	7.	9.
# Ships @ FCA2AD2	100	13.38	10.	12.	13.	13.	14.	15.	15.
# Ships @ FCA2AD3	100	6.94	6.	7.	7.	7.	7.	7.	7.

Figure 31. A2/AD Number of Ships at Force Closure

n. A2/AD Average Horsepower

Figure 32 provides a comparison of average horsepower needed to achieve force closure for the A2/AD datasets. Examination of the means for the datasets shows sufficient variation leading to the conclusion that there is statistical significance between the datasets. The means for average horsepower from the datasets closely aligned to the average horsepower input to the model. The input was 50,380 hp for A2/AD1, 44,758 hp for A2/AD2 and 49,298 hp for A2/AD3. The results confirm that the model calculated horsepower properly.



Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Avg HP @ FC A2AD1	100	50,684.21429	48,200.	51,314.28571	50,741.96429	51,314.28571	51,314.28571	51,314.28571	51,314.28571
Avg HP @ FC A2AD2	100	45,948.29305	42,376.	44,758.06667	45,560.42857	45,865.07692	46,526.61538	47,653.83333	47,653.83333
Avg HP @ FC A2AD3	100	54,611.07571	49,693.28571	54,979.	54,979.	54,979.	54,979.	54,979.	59,142.16667

Figure 32. A2/AD Average Horsepower

o. Summary

Table 18 provides a summary of the boxplot analysis for the output factors of the ExtendSim model. The HA/DR datasets were statically significant for fuel consumed and as such support the fuel consumption MOE. Specifically, when the force is augmented with commercial shipping the total fuel consumed increase on average by an additional 1% for all ships arriving at the seabase and an additional 8% for the ships that achieved force closure. This difference is a result of the larger, faster commercial ships arriving at the seabase first followed by the naval vessels. The commercial ships have higher horsepower and are able to travel at higher speeds. This results in additional fuel consumption. Given this, it is concluded that for the HA/DR ship packages there are no benefits gained in augmenting the fleet with commercial shipping. Fuel economy was not realized and force closure time was not significantly affected.

Table 18 also lists the results of the boxplot analysis for the A2/AD datasets. These datasets were statistically significant across the output factors for the ExtendSim model. In each factor, the dominant contributor was the addition of the Maersk AFSB. This ship provides a superior capability in terms of speed, and capacity. The addition of the Maersk reduced force closure time by 20% and mean total fuel consumption at force

closure by 22%. Distance traveled from SPOE to seabase, is another factor, which should be minimized to reduce the overall fuel consumed and time to force closure.

Table 18. Boxplot Statistical Significance Summary

	HA/DR	A2/AD
Force Closure Time	Not Significant	Significant
Total Fuel	Significant	Significant
Total Fuel at Force Closure	Significant	Significant
Average Speed	Not Significant	Significant
Average Distance Traveled	Not Significant	Significant
# Ships at Force Closure	Not Significant	Significant
Average Horse Power	Not Significant	Significant

Comparison of the recommendation for HA/DR and A2/AD appear to be contradictory. This is a result the definitions for force closure for HA/DR and A2/AD. Force closure for HA/DR was achieved when a preset amount of cargo was delivered from the SPOE to the seabase. A2/AD force closure was achieved when a percentage of the equipment density and personnel were delivered from the SPOE to the seabase. The additional complexity of the A2/AD force closure definition provides more variability in the ships arriving at the seabase to achieve force closure.

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VI. CONCLUSIONS

A. RESPONSES TO RESEARCH QUESTIONS

The following research questions guided the study:

(1) What transportation alternatives allow the fastest time to close at seabase?

The results of the simulations provide insight into how the alternative solutions may play out in reality and suggest which alternatives may allow the fastest time to close at the seabase. For the A2/AD mission profile, A2/AD3 demonstrated the fastest time to force closure. Due to the high capacity advantages provided by the commercial shipping assets, A2/AD3 was 14% faster than A2/AD2 and 77% faster than A2/AD1.

For the HA/DR mission profile, the separate scenarios showed only a 1% difference in force closure time.

(2) What is the trade space between time to close, fuel consumption, and available connector platforms?

When considering the A2/AD mission profile, it is clear that the fastest and most fuel-efficient transportation option is to take advantage of large commercial shipping assets that may already be stationed near the AO. However, these options may not always be available due to the nature of commercial shipping schedules. There is an inverse relationship between fuel consumption and force closure time when comparing the A2/AD1 and A2/AD2 scenarios. By mobilizing the MSC assets, time to close is reduced by nearly 36%; however, this added speed comes at a cost of nearly 36% increase in fuel consumption.

The HA/DR missions showed a less pronounced difference in shipping options. The simulation data suggested only a 1% difference in force closure times between the two scenarios. However, the HA/DR2 scenario, utilizing numerous commercial assets, showed a 16% increase in fuel consumption with no advantage in closure time. Based on this analysis, there is no benefit to supplement the force with commercial vessels.

(3) What are the critical parameters influencing the selection of sealift to transport a MEB to a seabase?

The regression analysis performed on the simulation results showed that the A2/AD and HA/DR missions were most influenced by sea state and the number of ships sailing, when considering fuel consumption. When time to force closure was considered, speed and distance traveled became the dominant factors. Although other parameters demonstrated significance in some of the mission profiles, they did not appear to apply to all scenarios. This suggests that some parameters may be specific to a particular scenario based on the unique situation and composition of force structure.

B. AREAS OF FURTHER RESEARCH

The research and analysis conducted as part of this capstone report focused on the *Close* phase of seabasing operations. Upon arrival at the seabase location and meeting force closure criteria for the defined mission, the *Close* phase transitions to the *Assembly* phase. During this phase, equipment and personnel transfer from the transport ships to connector platforms such as LCUs, LCACs, CH-53, MV-22, and AAVs. The transport ships are equipped with lift and transfer capabilities in the form of cargo cranes, roll-on/roll-off platforms, and literage platforms that facilitate the movement of equipment and personnel to the connector platforms. The transfer of equipment and personnel to the connector platforms during the *Assembly* phase is a time constraining function that affects the force's ability to reach the *Employment* phase to conduct operations from the seabase.

The ExtendSim model developed to support this research has the flexibility to analyze multiple shipping compositions and includes the number of connector platforms available (by type) for each ship. Extension of the simulation model to account for (1) available literage, (2) lift throughput of cargo cranes, (3) roll-on/roll-off capacity, and (4) transfer rates of personnel and equipment from each ship would provide data to determine the effect of ship composition alternatives on minimizing the assembly time of the seabase operation.

Chapter IV, Section C identified the impact on the MOEs due to the use of different SPOEs and resulting shorter distances from SPOE to seabase in the alternative

solutions. To reduce the impact of the different SPOEs in each alternative solution, future analysis should focus on adding homeports in Hawaii and Australia for U.S. Navy amphibious ships. This would provide a set of SPOEs with fixed distances from which trade-offs between the composition of commercial, allied nation, MSC, and amphibious ships could be considered regarding force closure time and fuel consumption.

Staging prepositioned cargo containers throughout the MARFORPAC area of operations to support the range of military operations is another area of research regarding augmentation of amphibious shipping. In addition to MPF shipping based in Saipan and Guam, prepositioned cargo containers with tailored force deployment packages staged in various locations in the MARFORPAC area of operations could potentially provide another option for MAGTF planners to use alternative shipping methods to minimize force closure and assembly time as well as reduce fuel consumption. Analysis of the composition, size, and location of these prepositioned cargo containers using scenarios similar to those used in this capstone could provide insight into the viability of this concept.

C. CONCLUSION

This capstone utilized systems engineering processes, model-based systems engineering tools, and modeling and simulation tools and techniques to examine the impact of augmenting U.S. Navy amphibious shipping with alternative shipping platforms to support MEB seabasing operations. Alternative shipping compositions of U.S. Navy amphibious, commercial, MSC, and allied nation ships were applied to A2/AD and HA/DR alternative solutions to determine the factors that influenced force closure time and fuel consumption in support of seabasing operations.

Using modeling and simulation and statistical analysis, the capstone team determined that augmentation of commercial, allied, and MSC ships with U.S. Navy amphibious ships significantly reduced force closure time and fuel consumption for the A2/AD mission when compared to using only U.S. Navy amphibious ships. The team attributes this reduction in force closure time and fuel consumption to the reduced distance traveled from the SPOE to the seabase for the commercial and allied nation ships

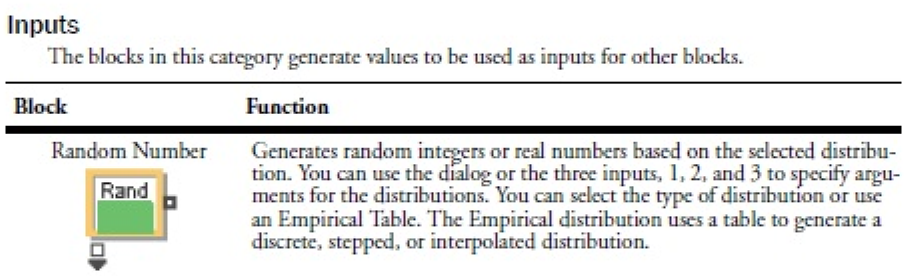
and the speed of these ships. However, the augmentation of commercial and allied nation ships in support of the HA/DR mission showed no statistical significance when compared to using MSC and U.S. Navy amphibious ships with regards to force closure time and fuel consumption. Even though the A2/AD and HA/DR missions had unique and significantly different criteria for determining force closure, regression analysis demonstrated that both mission types were influenced by the sea state (an uncontrollable environmental factor) and the number of ships at force closure.

The analysis performed in this capstone demonstrated the viability of considering the augmentation of commercial, allied nations, MSC, and U.S. Navy amphibious shipping as part of the FDP&E process to reduce force closure time and fuel consumption. It is the recommendation of the capstone team that the Naval fleet not be augmented with commercial ships when executing a HA/DR mission unless a commercial ship is identified which exhibits enhanced fuel economy and is able to travel at high speeds. The team also recommends augmentation of commercial or naval ships that exhibit high speed and high capacity when executing an A2/AD mission. Within the vast MARFORPAC area of operations, factors such as ship speed and distance from SPOE to seabase are key considerations that MAGTF planners should take into account when determining the feasibility of using alternative shipping platforms. Even though the MAGTF planner may take advantage of a faster force closure time or reduced fuel consumption, through the use of alternative shipping platforms, the capability to provide ship-to-shore connectors and the capacity to transfer personnel and equipment to these connectors is the next step the MAGTF planner must consider.

APPENDIX A. EXTENDSIM MODEL DESCRIPTION

A. EXTENDSIM COMPONENT DESCRIPTION

This section of the appendix addresses the different model blocks that were utilized in ExtendSIM to develop a model that could simulate different A2/AD and HA/DR scenarios. Specifically, this section only covers the basic functions of the different blocks that were used in the simulation. In order to understand how the different blocks are used within the simulation it is first important to understand their basic functions. The block descriptions, names, and general functions are described in Figures 33–41 and were taken from the *ExtendSIM9 User Guide*.

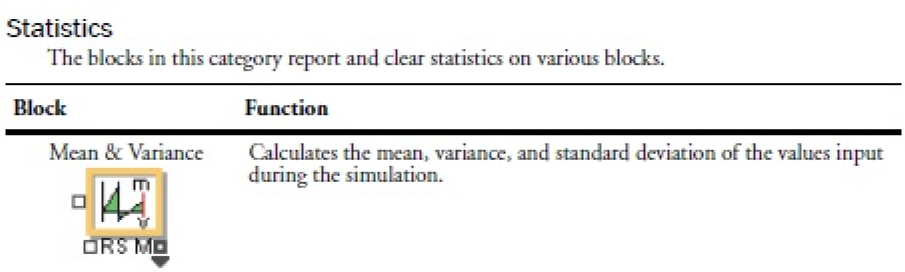


Inputs

The blocks in this category generate values to be used as inputs for other blocks.

Block	Function
Random Number	Generates random integers or real numbers based on the selected distribution. You can use the dialog or the three inputs, 1, 2, and 3 to specify arguments for the distributions. You can select the type of distribution or use an Empirical Table. The Empirical distribution uses a table to generate a discrete, stepped, or interpolated distribution.

Figure 33. Random Number Generator Block



Statistics

The blocks in this category report and clear statistics on various blocks.

Block	Function
Mean & Variance	Calculates the mean, variance, and standard deviation of the values input during the simulation.

Figure 34. Mean and Variance Statistics Block

Queues

The blocks in this category hold, sort, and rank items.

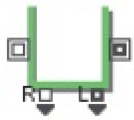
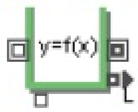
Block	Function
Queue 	Queues items and releases them based on a user selected queuing algorithm, such as Resource pool queue, Attribute value, First in first out, Last in first out, and Priority. Options include reneging and setting wait time. If you need more advanced control over the queueing algorithm, consider using the Queue Equation block, below.
Queue Equation 	Queues items and releases them based on the results of user entered equations. The result(s) of the equations can optionally be assigned to properties of the item

Figure 35. Queue Blocks

Data Access

The blocks in this category are used to access and store data in your models.

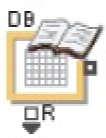
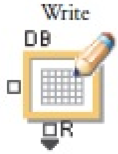
Block	Function
Read 	Reads data from a data source to be used in a model. The data sources supported are the ExtendSim database, global arrays, Excel workbooks, Text Files, and local tables. You can specify whether you want to read a single number or a row or column of data and you can specify when the data should be read.
Write 	Writes data from a model to a data destination. The data destinations supported are: ExtendSim databases, global arrays, Excel Workbooks, Text Files, and Local Tables. You can specify whether you want to write a single number or a row or column of data, and when the data should be written.

Figure 36. Database Read and Write Blocks

Batching

The blocks in this category are used to join and divide items.

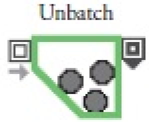
Block	Function
Batch 	Allows items from several sources to be joined as a single item. Useful for synchronizing resources and combining various parts of a job ("kitting").
Unbatch 	Produces multiple items from a single input item. This block can be used to disassemble a kit, break a message packet into component messages, route the same message to several places, or distribute copies of invoices.

Figure 37. Batch and Unbatch Blocks

Properties

The blocks in this category assign and display item properties.

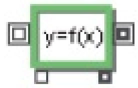
Block	Function
Equation(I) 	Calculates equations when an item passes through. The equations can use multiple inputs and properties of the item as variables, and the result(s) of the equations can be assigned to multiple outputs and properties of the item.

Figure 38. Equation Block

Activity

The blocks in this category are used to process items in the model.

Block	Function
Activity 	Holds one or more items and passes them out based on the process time and arrival time for each item.

Figure 39. Activity Block

Routing

The blocks in this category move items to the correct place.

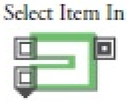
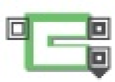
Block	Function
Create 	Provides items or values for a discrete event simulation at specified interarrival times. Choose either a distribution or a schedule for the arrival of items or values into the model.
Exit 	Passes items out of the simulation. The total number of items absorbed by this block is reported in its dialog and at the value output connectors.
Select Item In 	Selects items from one input to be output based on a decision.
Select Item Out 	Selects which output gets items from the input, based on a decision

Figure 40. Movement Blocks

Executive

The block in this category is needed in every discrete event and discrete rate model to handle events.

Block	Function
Executive 	This block must be placed to the left of all other blocks in discrete event and discrete rate models. It does event scheduling and provides for simulation control, item allocation, attribute management, and other discrete event and discrete rate model settings.

Figure 41. Executive Block

B. EXTENDSIM SIMULATION MODEL DESCRIPTION

This section aims to cover the general process flow within the model, as well as provide a high level description of the actions that are taking place as entities are processed through key sections of the model. Figure 42 provides an overall view of the model that was developed for this capstone and was developed to be flexible to support different vessel configurations. This constitutes the model in its entirety. Although showing three separate levels, the model is in fact a single continuous chain. Entities are processed from left to right and proceed to the next lower level after completing the row.

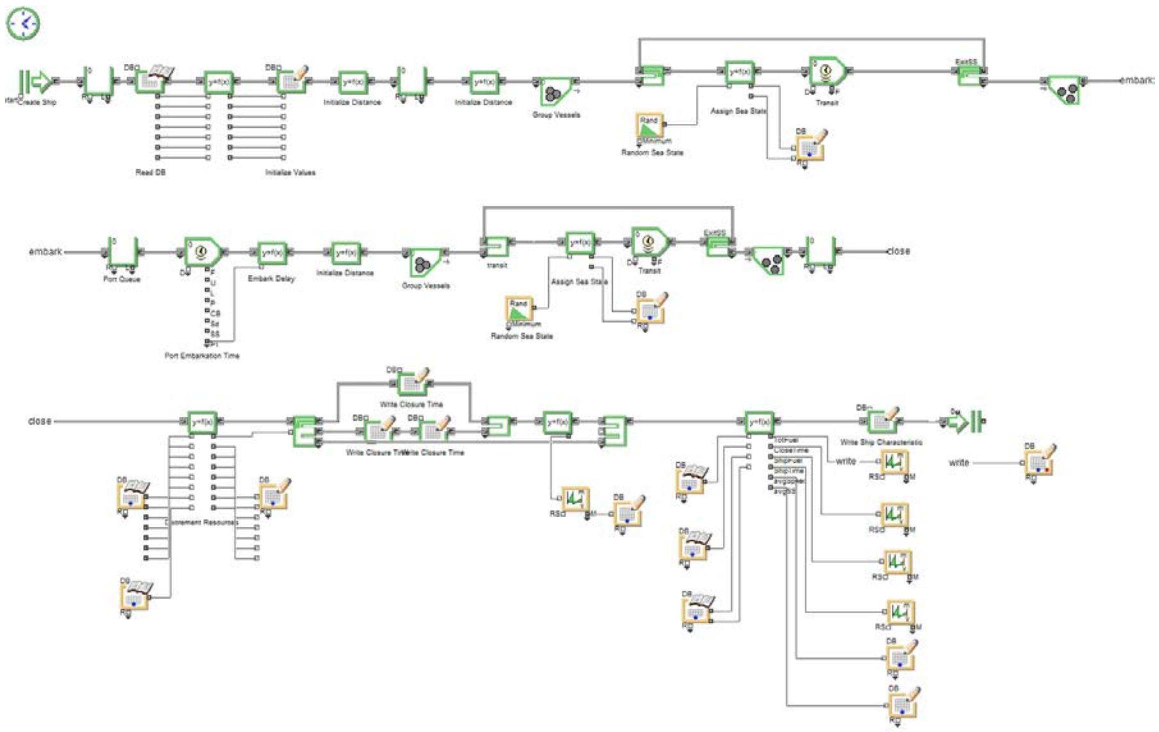


Figure 42. ExtendSIM Model

Figure 43 is the first of the key sections to be noted. This particular section of model blocks is extremely important. This is where the number of entities that will be modeled are initialized and assigned values from the database when created. The system assigns batch values to the entities for vessels that will be travelling in groups, as well as vessel physical characteristics, such as maximum speed, horsepower, fuel, water, people, and cargo capacity to name a few. The system assigns the amount of resources required to meet closure depending on the mission type designated in the database, which is 80% of the MEB EDL for A2/AD and a certain amount of food water and supplies for HA/DR. The ***mission requirements*** table in the database is used to specify the exact requirements. This table is copied to the ***resources*** table for decrementing as ships arrive at the seabase to determine closure. The distance to the port of embarkation and the distance to the seabase are also initialized in these blocks.

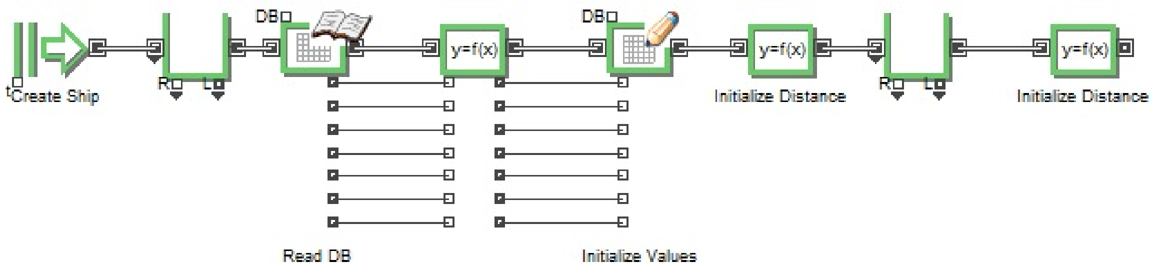


Figure 43. Initialize and Assign Vessel Attributes

The section of blocks represented in Figure 44 attempts to stochastically model the sea state in transit to the SPOE. Before assigning a sea state to each vessel, the model checks to see if ships are assigned to groups. This ensures that the vessels travelling in groups are assigned the same sea state within the model. Once grouped, the vessels are assigned a random sea state, which has an impact on the overall vessel speed in transit to the SPOE. The database writes the sea state, used at the end of the simulation to determine the average sea state, and updates the database to reflect the total time travelled, total fuel used, distance traveled, as well as the distance remaining. As long as the vessels have yet to arrive at the SPOE, this is recalculated every 12 hours or the time to reach the SPOE, whichever is less, to factor in variability in the model. It then exits the loop and ungroups the vessels to simulate embarking at the SPOE. An identical set of blocks is used to model the vessels in transit to the seabase.

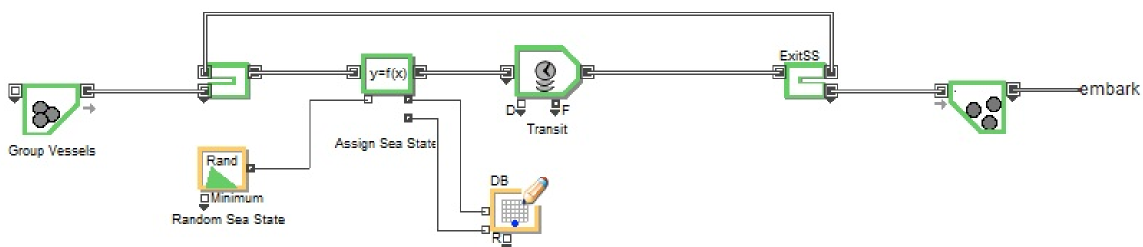


Figure 44. Seastate and Batching Model Segment

Figure 45 models the embarkation aspect of the model. The Port Embarkation Time activity block uses a normal distribution with the average of 29.64 hours and a standard deviation of 19.27 hours in order to simulate average turnaround time of ports in Oceania.

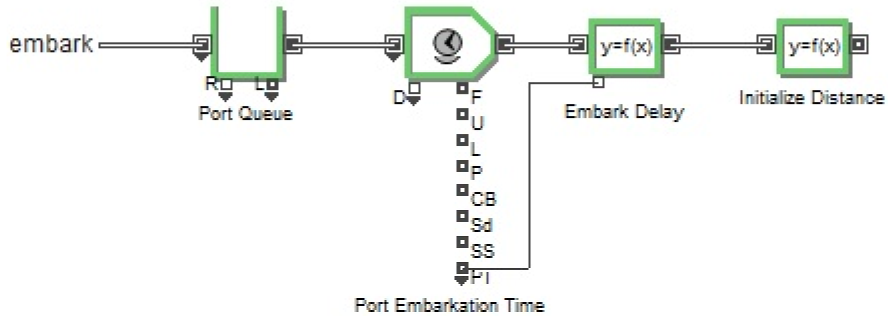


Figure 45. SPOE Activity Model

Figure 46 describes the blocks used to decrement the resources carried by the vessels from the total mission requirements. If closure was previously not determined and there are no additional resources required, we have reached closure.

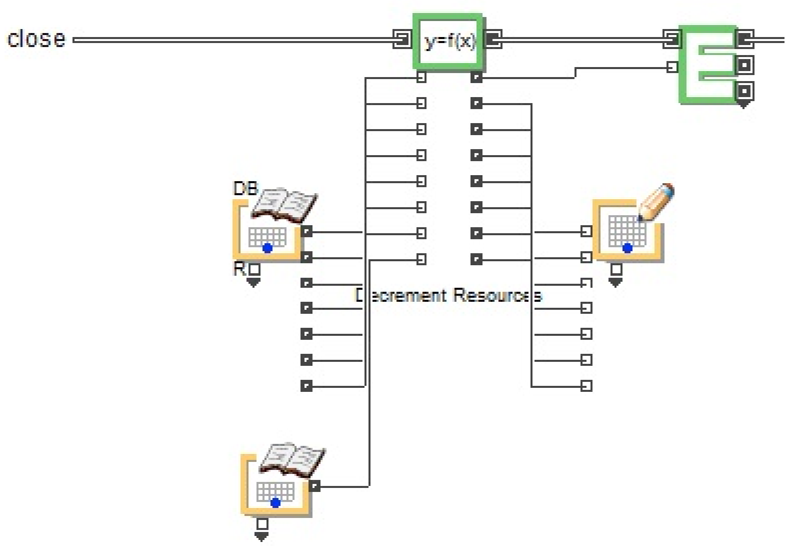


Figure 46. Decrement Resources Model Segment

Figure 47 shows the logic used to route the vessel depending on whether closure has not been reached, closure has just been reached, or closure had previously been reached, from top to bottom of the select out block, respectively. If closure has not been determined, the assets arrived at the seabase are incremented in the ***output*** database. If

closure has just been reached, in addition to incrementing the resources, the closure time is written. If closure had previously been written, nothing else is done.

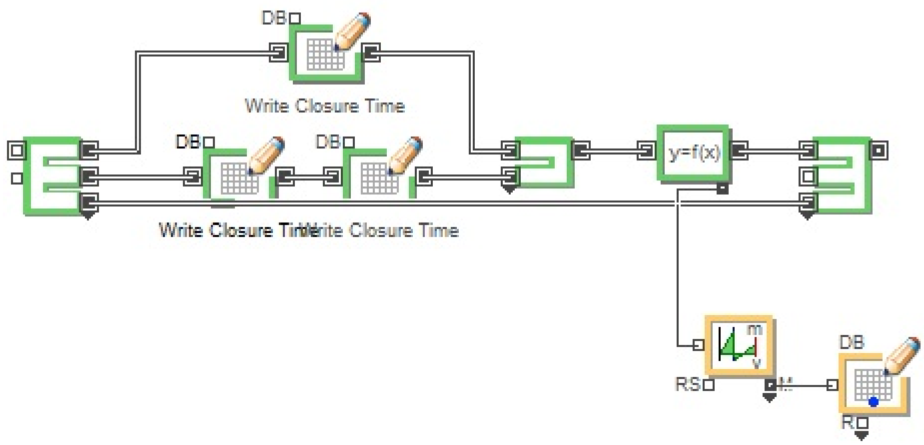


Figure 47. Force Closure Model Segment

Figure 48 shows the blocks used to read the vessel's total time, distance travelled and total fuel, in kilo-gallons and written to the output table of the database in order to determine the total aggregate number. The average speed and average sea state during the simulation are also calculated.

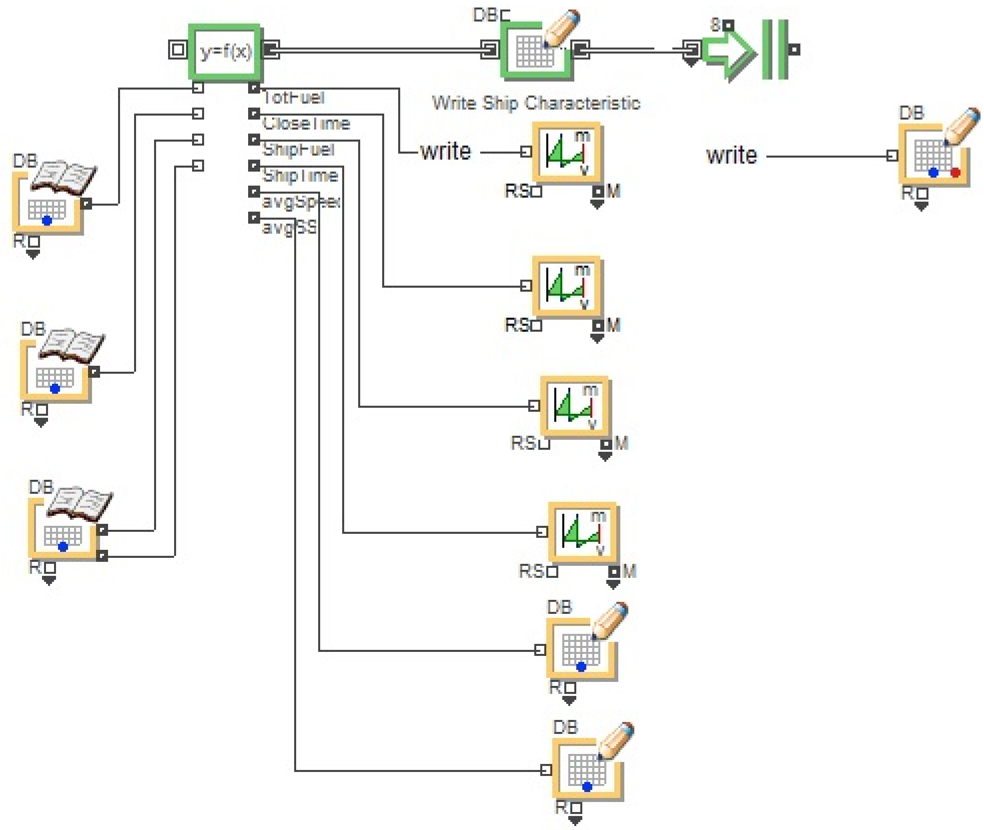


Figure 48. Output Write Model Segment and Simulation End

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APPENDIX B. MODEL ANALYSIS

Figure 49 represents a sample of the data output by the simulations for the HA/DR1 scenario. The Microsoft Excel spreadsheets include the output for each parameter listed in the headings and data collected for each of the 100 runs performed by the simulation. The sample output included Figure 49 has been truncated due to space constraints in the report format.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Force Closure Time	Total Fuel (all ships)	Total Fuel @ FC	Avg Seastate	Avg Speed (NM/H)	Average NM Travelled each ship @ FC	# Ships @ FC	Avg HP @ FC	LCAC	LCU	Aircraft	Closed	Seastate Changes	SeaState Sum
2	223.79	4266789.76	968980.97	1.00	11.76	2632.00	2.00	56517.00	0.00	0.00	0.00	1.00	102.00	176.00
3	214.71	4192249.26	1740379.57	1.00	12.40	2661.50	4.00	54008.50	7.00	5.00	19.00	1.00	106.00	200.00
4	181.36	4456299.93	1058945.79	1.00	14.51	2632.00	2.00	56517.00	0.00	0.00	0.00	1.00	100.00	154.00
5	221.06	4214206.10	2270995.73	1.00	12.01	2655.60	5.00	55329.20	7.00	5.00	19.00	1.00	104.00	188.00
6	185.94	4288970.60	1554090.02	1.00	14.16	2632.00	3.00	57882.00	0.00	0.00	0.00	1.00	102.00	192.00
7	230.20	4072935.73	1760940.46	2.00	11.56	2661.50	4.00	54008.50	7.00	5.00	19.00	1.00	106.00	222.00
93	203.98	4179188.25	976911.11	2.00	12.90	2632.00	2.00	56517.00	0.00	0.00	0.00	1.00	102.00	212.00
94	197.83	4272378.94	2335175.06	1.00	13.42	2655.60	5.00	55329.20	7.00	5.00	19.00	1.00	104.00	174.00
95	205.33	4121523.70	2182288.82	2.00	12.93	2655.60	5.00	55329.20	7.00	5.00	19.00	1.00	104.00	216.00
96	187.42	4274223.89	1019778.50	1.00	14.04	2632.00	2.00	56517.00	0.00	0.00	0.00	1.00	100.00	188.00
97	213.73	4318571.79	1795290.13	1.00	12.45	2661.50	4.00	54008.50	7.00	5.00	19.00	1.00	102.00	198.00
98	181.35	4461414.74	1060183.17	1.00	14.51	2632.00	2.00	56517.00	0.00	0.00	0.00	1.00	100.00	138.00
99	213.03	4420235.28	1040509.69	1.00	12.36	2632.00	2.00	56517.00	0.00	0.00	0.00	1.00	98.00	170.00
100	198.38	4193529.77	1831364.50	2.00	13.42	2661.50	4.00	54008.50	7.00	5.00	19.00	1.00	102.00	212.00
101	197.52	4168690.37	2252785.07	1.00	13.44	2655.60	5.00	55329.20	7.00	5.00	19.00	1.00	104.00	192.00
102														

Figure 49. HA/DR1 Simulation Sample Data

A sample of the initial Analysis of Variance for the HA/DR1 simulation is provided in Figure 50. By examining the p-values provided in this initial regression analysis, the team determined that Average Speed and Average NM (distance) Traveled were the contributing factors influencing Force Closure Time for this simulation.

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.997089991					
R Square	0.994188451					
Adjusted R Square	0.993746268					
Standard Error	1.329499566					
Observations	100					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	7	27818.96768	3974.13824	2248.363726	6.7141E-100	
Residual	92	162.6163569	1.767569096			
Total	99	27981.58404				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	222.8929035	21.3056907	10.46166053	2.45726E-17	180.5779627	265.2078443
Total Fuel (all ships)	1.73042E-06	2.0767E-06	0.833257183	0.406857769	-2.39408E-06	5.85493E-06
Total Fuel @ FC	1.45861E-06	3.79314E-06	0.38453958	0.701466015	-6.07489E-06	8.99211E-06
Avg Seastate	0.976371975	0.422463504	2.311139224	0.023059026	0.13732299	1.815420959
Avg Speed (NM/H)	-16.90494545	0.172110798	-98.22129502	6.06171E-95	-17.24677236	-16.56311855
Average NM Travelled	0.0752712	0.002432215	30.94758966	2.00709E-50	0.070440611	0.08010179
# Ships @ FC	-0.932499074	1.694964921	-0.550158332	0.583544051	-4.298845711	2.433847563
Avg HP @ FC	-9.84429E-05	0.000200765	-0.490338021	0.625062129	-0.00049718	0.000300295

Figure 50. HA/DR1 Force Closure Time Initial Regression Analysis

Given that only two factors are influential in this model, the team performed a second regression analysis examining only the influential variables, speed and distance. Figure 51 is a sample of this second analysis performed on the HA/DR1 data and provides more refined coefficients that could be used to construct a prediction equation for Force Closure Time of the HA/DR1 scenario.

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.996921776					
R Square	0.993853028					
Adjusted R Square	0.993660935					
Standard Error	1.338539419					
Observations	100					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	3	27809.58201	9269.86067	5173.814763	5.6347E-106	
Residual	96	172.0020266	1.791687777			
Total	99	27981.58404				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	226.9027125	4.751711159	47.75178982	1.05873E-68	217.4706404	236.3347846
Avg Speed (NM/H)	-16.85889705	0.139439243	-120.904967	1.0209E-106	-17.13568176	-16.58211234
Average NM Travelled	0.07412349	0.00182604	40.5924686	3.01652E-62	0.070498829	0.077748152

Figure 51. HA/DR1 Force Closure Time Final Regression Analysis

All other simulation scenarios provided similar data outputs and were subjected to the same data analysis in order to determine which factors influenced the outcome of the simulations. Separate analyses were performed in consideration of Force Closure Time and Fuel at Force Closure. This data is tabulated in Microsoft Excel spreadsheets and is available upon request to the MARFORPAC capstone team.

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